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National Aerospace Laboratory NLR

AMS Tracker Thermal Control Subsystem

TTCS Heater Specifications

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Issue 4.0
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An electronic version of this document is available on the AMS TTCS website: https://ams-ttcs.nlr.nl

Document change log

Change Ref.	*Section(s)*	*Issue 1.0*
-	All	Initial issue

Change Ref.	*Section(s)*	*Issue1.1*
E-mail Mike Capell	Section 5.1.2	Update figures
Added for clarity	Section 5.1.3	Include currents in tables
Pdf-problem	Section 4.1.2	Change format

Change Ref.	*Section(s)*	*Issue1.2*
Design changes update	all	Updates of heaters specifications Implementation of cold-orbit heaters

Change Ref.	*Section(s)*	*Issue1.3*
Design changes update	all	Update schematics Figure 3-1 and Figure 3-2 Updates of heaters specifications and designs TS design implementations

Change Ref.	*Section(s)*	*Issue1.4*
Spec. changes update	all	Update schematics Figure 3-1 and Figure 3-2 Codes thermocoax connectors changed Foil heater in liquid line health heaters changed Typos in 120 V radiator heater specifications corrected Thermostats inside box changed to Comepa

Change Ref.	*Section(s)*	*Issue1.5*
Spec. changes update	all	AWG size corrected to AWG 26 table Table 4-3 Definition of all terminal blocks (changed for wire sizes) Appendices added on thermostat and TB's

Change Ref.	*Section(s)*	*Issue2.0*
	Section 1	Deleted OHP including heaters
	Page 7 and 8	Updated Figures 3-1 and 3-2

Change Ref.	*Section(s)*	*Issue3.0*
	Section 3	Update Loop Schematics
		Update electronics overview
	Section 4.5	Updated liquid line heater design
Change Ref.	*Section(s)*	*Issue4.0*
	Section 3	Update Loop Schematics
		Update electronics overview
	Section 4.1, 4.2, 4.3, 4.4	Include final design and pictures of implementation
	Section 4.5	Updated liquid line heater design with thermostats
	Section 5	Update design to final status
	Appendices	Heater design details added.
		Box wiring schematic added.

Summary

This document contains the specifications of the TTCS heaters. The objective is to summarise the information for electrical and mechanical design engineers as input to their subsystem designs. This document needs to be maintained and detailed where needed and should be used as a design reference document.

Contents

(89 pages in total)

1 Scope of the document

The document describes the heater specifications of the TTCS. The objective of the document is to act as a reference document for electrical and mechanical and thermal subsystem design. It needs to be updated and detailed when heater design changes are implemented.

The following components are specified:

- Pre-heaters (in TTCS boxes)
- Accumulator operational heaters (in TTCS boxes)
- Accumulator emergency heaters (in TTCS boxes)
- Accumulator ground test heaters (in TTCS boxes)
- TTCB radiator LSS ground test heaters (in TTCS boxes)
- Start-up heaters (in TTCS boxes)
- TTCS liquid line heaters (on condesner inlet and outlet lines)
- Cold orbit heaters (in TTCS boxes)
- Tracker radiator and TTCS condenser heaters (120 V)

2 Reference documents

RD-1	NLR-Memorandum TTCS Condenser Freezing Test Report	AMSTR-NLR-TN-039-Issue03
RD-2	NLR-Memorandum TTCS Safety Approach	AMSTR-NLR-TN-044-Issue01
RD-3	NLR-Memorandum TTCS System Design Description Summary	AMSTR-NLR-TN-30-Issue03

3 System overview

In Figure 3-1 and Figure 3-2 the primary and secondary loop schematics are shown. These lay-outs can be used as a reference to understand the operation and interactions of the components discussed. An electronics schematic is shown in Figure 3-3. This is an overall block diagram and shows the electrical connections of the components in the TTCS boxes.

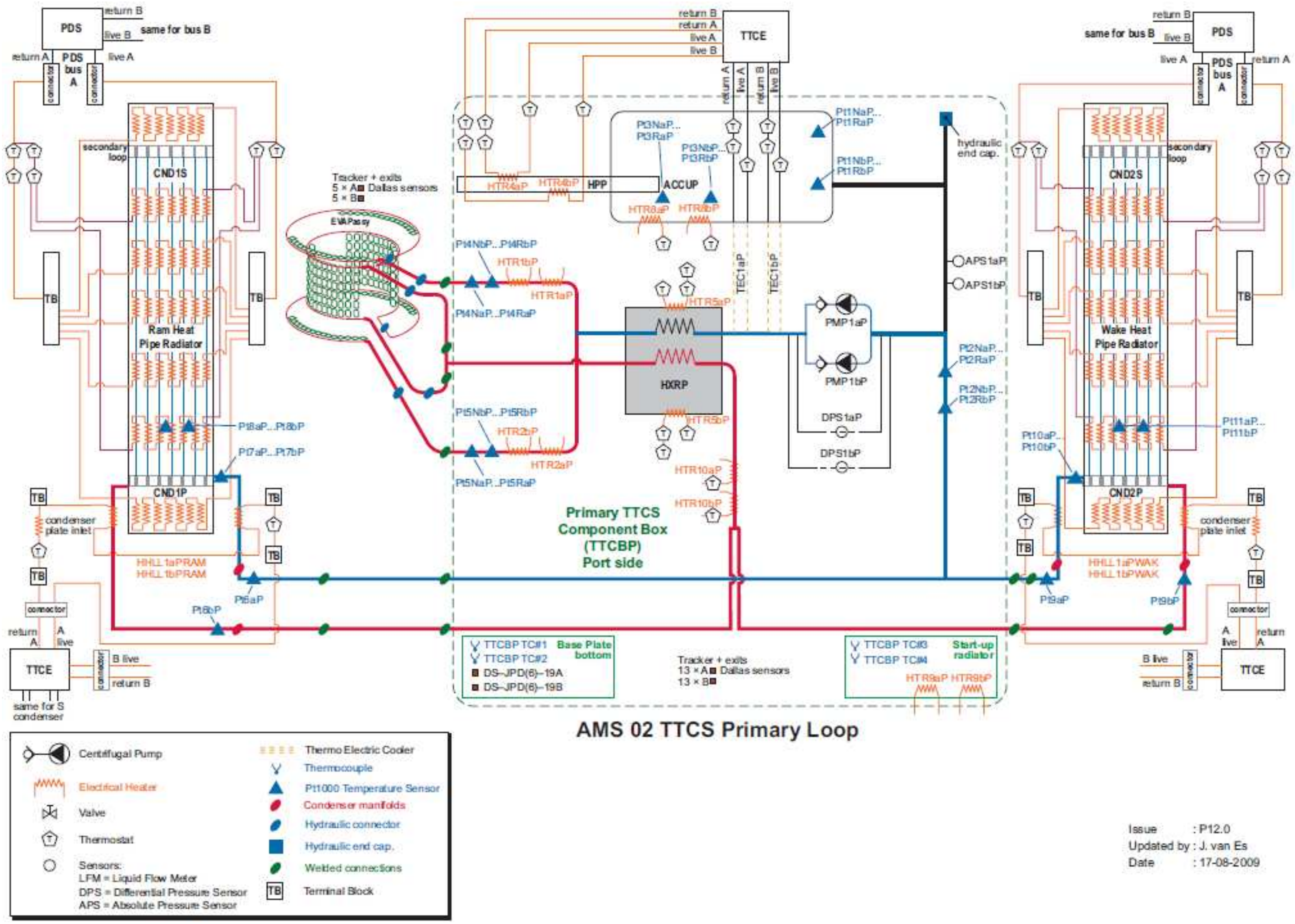


Figure 3-1: TTCS Primary loop lay-out

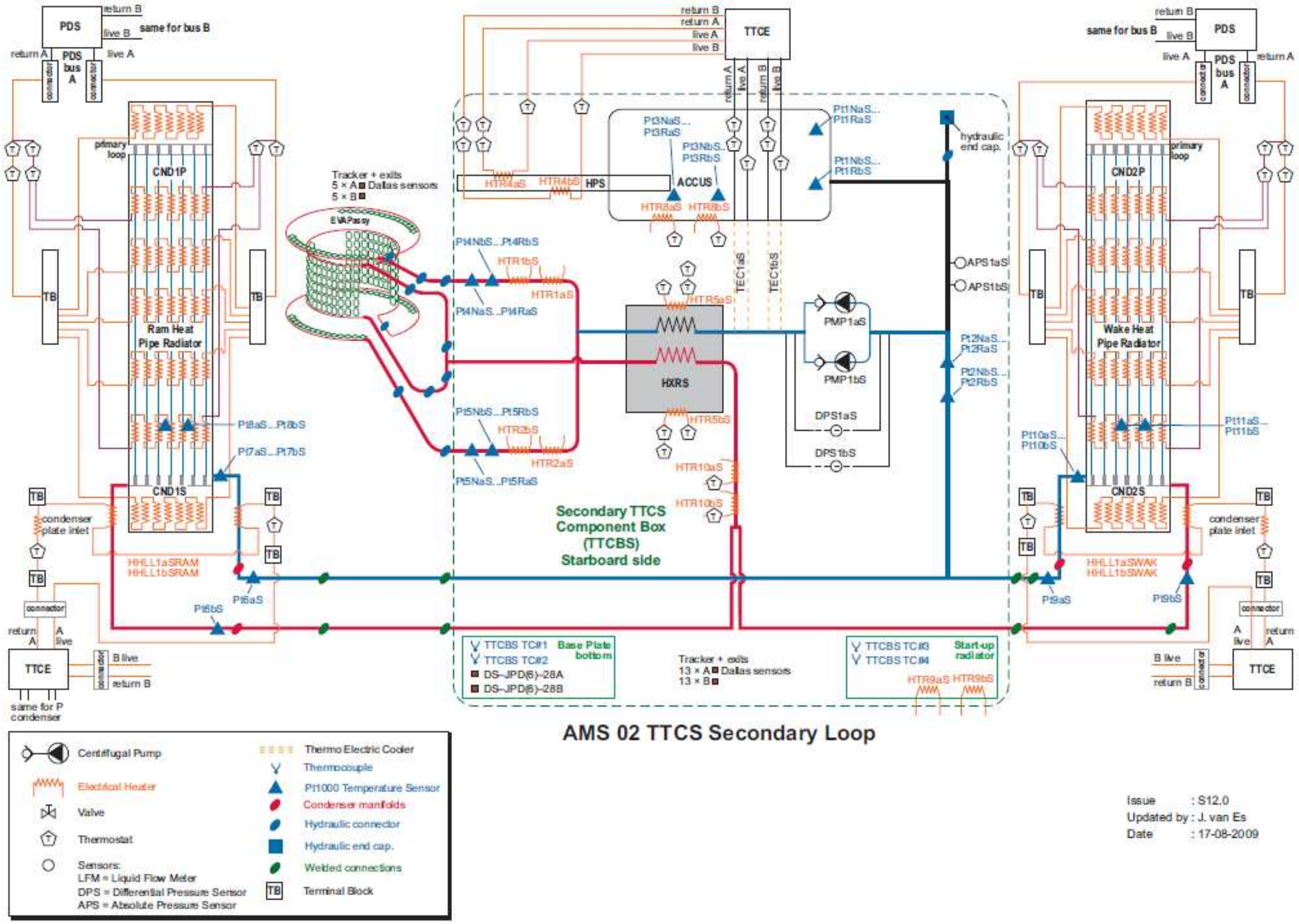


Figure 3-2: TTCS Secondary loop lay-out

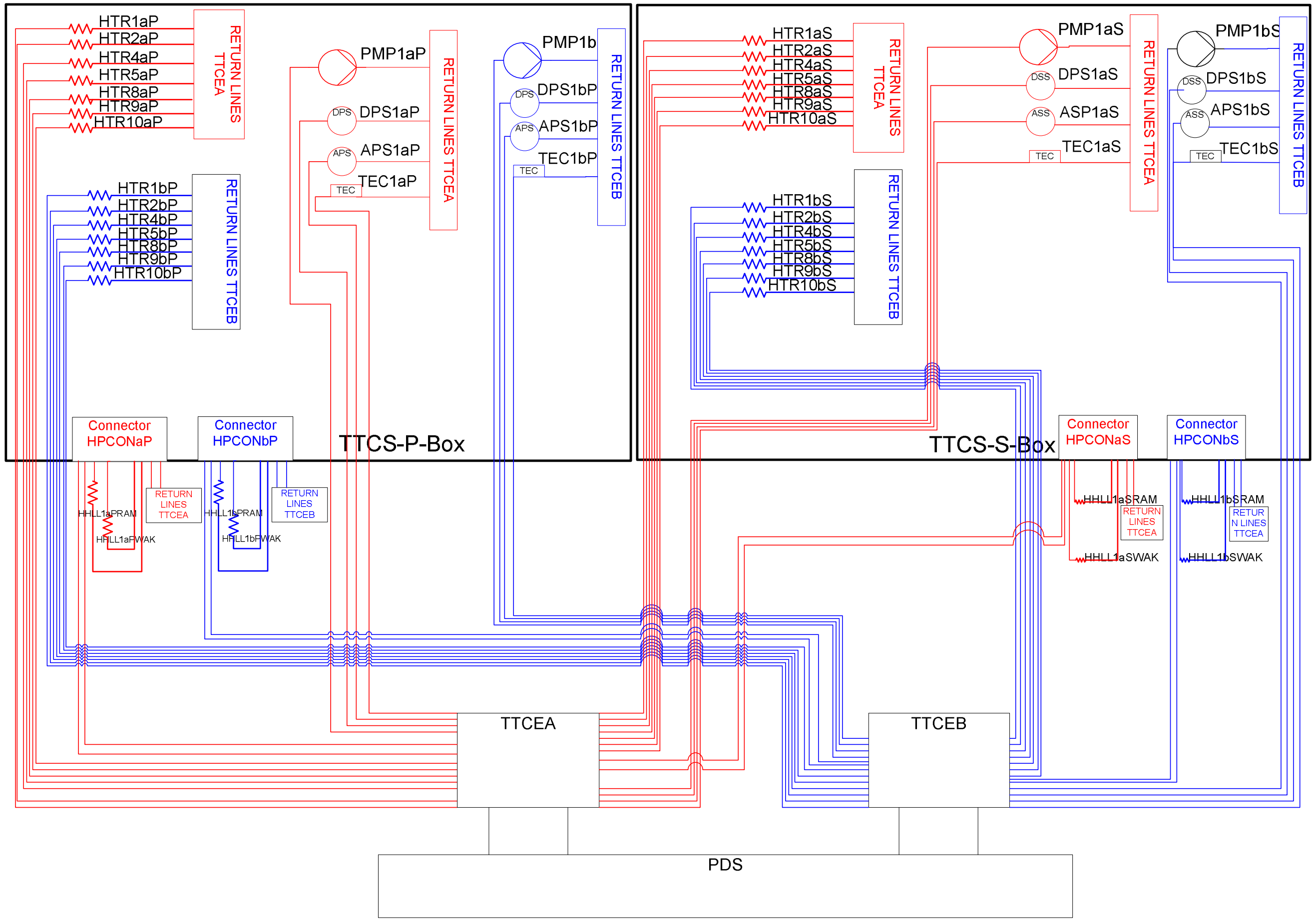


Figure 3-3: TTCS Electronics Schematics (Thermostats and Pt1000's are not included in this figure)

3.1 TTCS Heater Overview

In Table 3-1 an overview of the heaters and purpose of the heaters is given:

Heater name	Control		Purpose	Power/ Heater @28Vol	Comp. List Indication
	Thermo-stat	S/W control			
TTCS 28 Volt heaters					
Pre-heaters		X	Raise sub-cooled liquid to TTCS set-point	8.9	HTR1aP, HTR2aP, HTR1bP, HTR2bP HTR1aS, HTR2aS, HTR1bS, HTR2bS
Accumulator Control heaters	XX	X	Keep accumulator (TTCS) at set-point & Quick raise of accumulator set-point	37.5	HTR4aP, HTR4bP, HTR4aS, HTR4bS
Accumulator control heaters (ground testing)	XX	X	Keep accumulator (TTCS) at set-point & Quick raise of accumulator set-point	40.2	HTR8aP, HTR8bP, HTR8aS, HTR8bS
Start-up heaters	XX	X	Raise TTCS liquid flow from – 40 °C to –20°C during start-up (and cold orbitsTBD)	50	HTR5aP, HTR5bP, HTR5aS, HTR5bS
TTCS liquid line heaters		X	Defrost the TTCS condenser lines	16 (13.6 + 2.4)	HHLL1aP_RAM,HHLL1aP_RAM, HHLL1bS_RAM,HHLL1bS_RAM, HHLL1aP_WAK,HHLL1aP_WAK, HHLL1bS_WAK, HLL1bS_WAK,
TTCS LSS heaters (NON-FLIGHT)		X	To keep TTCB radiator > -40 °C during LSS testing	N/A 42.3 W @ 50 V	HTR9aP, HTR9bP, HTR9aS, HTR9bS
Cold Orbit Heaters	XXX	X	Prevent Freezing in condenser @ Cold Orbits	60	HTR10aP,HTR10bP, HTR10aS, HTR10bS

TTCS 120 V heaters					
Tracker radiator and condenser heaters RAM	X		Defrost Tracker radiator NH_3 HP's and CO_2 condenser	175.75	HHCONRAMP1A..HHCONRAMP8A HHCONRAMP1B..HHCONRAMP8B HHCONRAMS1A..HHCONRAMS8A HHCONRAMS8B..HHCONRAMS8B + TRACKER RADIATOR HEATERS
Tracker radiator and condenser heaters WAKE	X		Defrost Tracker radiator NH_3 HP's and CO_2 condenser	175.75	HHCONWAKP1A..HHCONWAKP8A HHCONWAKP1B..HHCONWAKP8B HHCONWAKS1A..HHCONWAKS8A HHCONWAKS8B..HHCONWAKS8B + TRACKER RADIATOR HEATERS

Table 3-1: TTCS Heater overview

Details on the numbers of heaters, locations and electronics schematics can be found in the specific heater sections.

X = Nominal control
XX = Additional safety control (outside operational TTCS temperature limits)
XXX = Additional mission success control (outside operational TTCS temperature limits)

The radiator heaters run at 120 VDC from the PDS. The main heaters are supplied by the ISS/PDS A and the redundant heaters are supplied by the redundant ISS/PDS B.
The other heaters run from the 28VDC supplied by the PDS to the TT-Crate (TTCE). The TTCE has a nominal and redundant feed (TTCE A and TTCE B). The TTCE A (main TTCE) can be supplied by both A and B of the PDS. The same is applicable for the TTCE B (redundant TTCE).

The power supplied from the TTCE is @ a nominal voltage of 28.0 Volts (min: 26.5 Volts max: 29.5 Volts). All the heaters are sized with the nominal voltage (28.0 Volts) except for the heaters with have to output a minimum power output even @ minimum voltage, these are sized with the minimum voltage (26.5 Volts).

4 TTCS 28 V Heater Design

The TTCS system is complete redundant meaning two identical loops are present on AMS02. The primary loop is located on the Port side and the Secondary loop is located on the Starboard side. The heater design for both the TTCS loops is exact similar except for some mirrored parts. The heater design is identical and therefore only one of the two loops is shown. Only in cases a difference has infuence on the heater design it will be mentioned.

4.1 Pre-heaters (in TTCS boxes)

The objective of the pre-heaters is to raise the CO_2 temperature to the set-point temperature.

4.1.1 Pre-heater location

The pre-heaters are located in the TTCS-boxes after the split of the evaporator tubing (see Figure 3-1 and Figure 3-2).

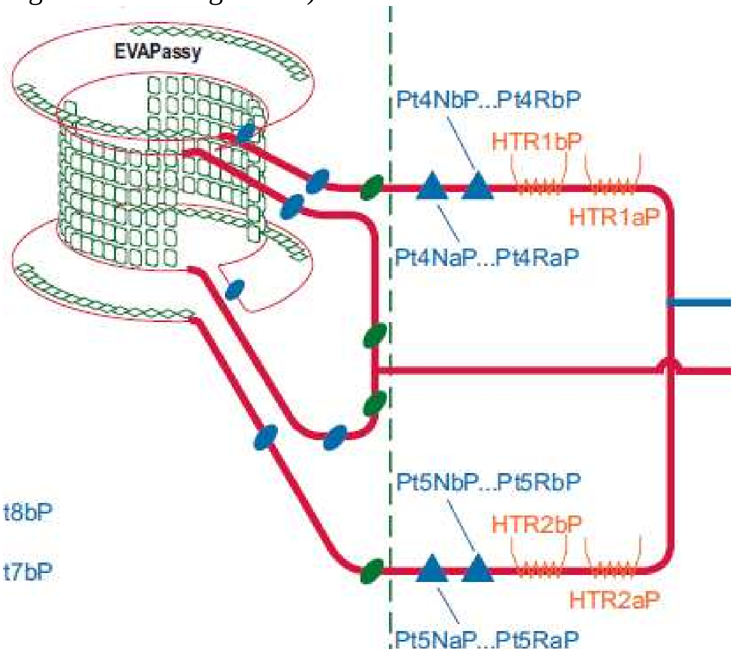


Figure 4-1: Detail of pre-heater section in TTCS schematics

At both branches a redundant pre-heater is located. One of the evaporator branches is routed to the upper Tracker and the other to the lower Tracker. The pre-heater section will be located directly on the TTCS base-plate and the heaters will be connected to a small copper block brazed to the TTCS tubes.

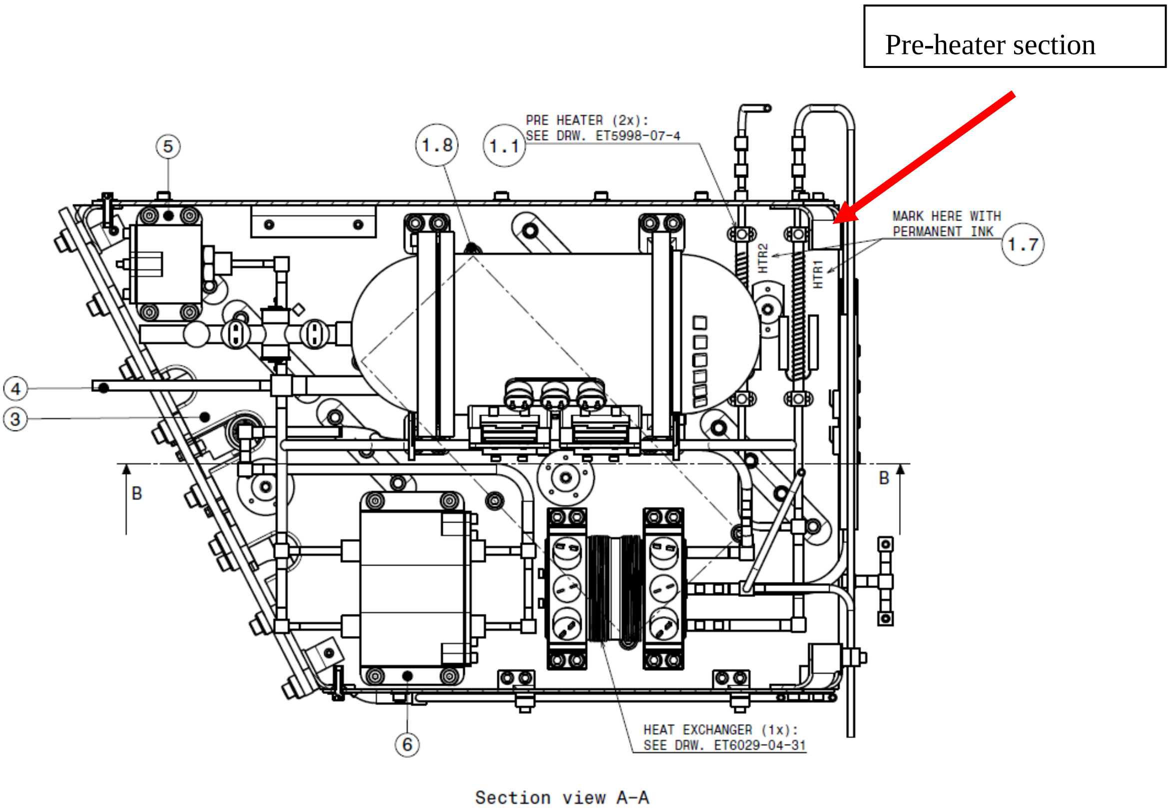


Figure 4-2: Pre-heater location on the base-plate

The A and B heater wires are both attached to the same tube locations as can be seen in Figure 4-3.

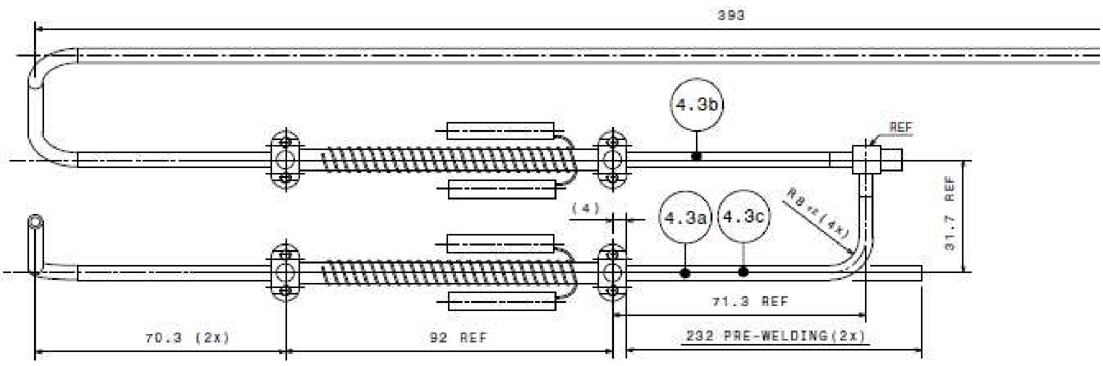


Figure 4-3: Pre-heater section design HTR1aP, HTR1bP, HTR2aP, HTR2bP

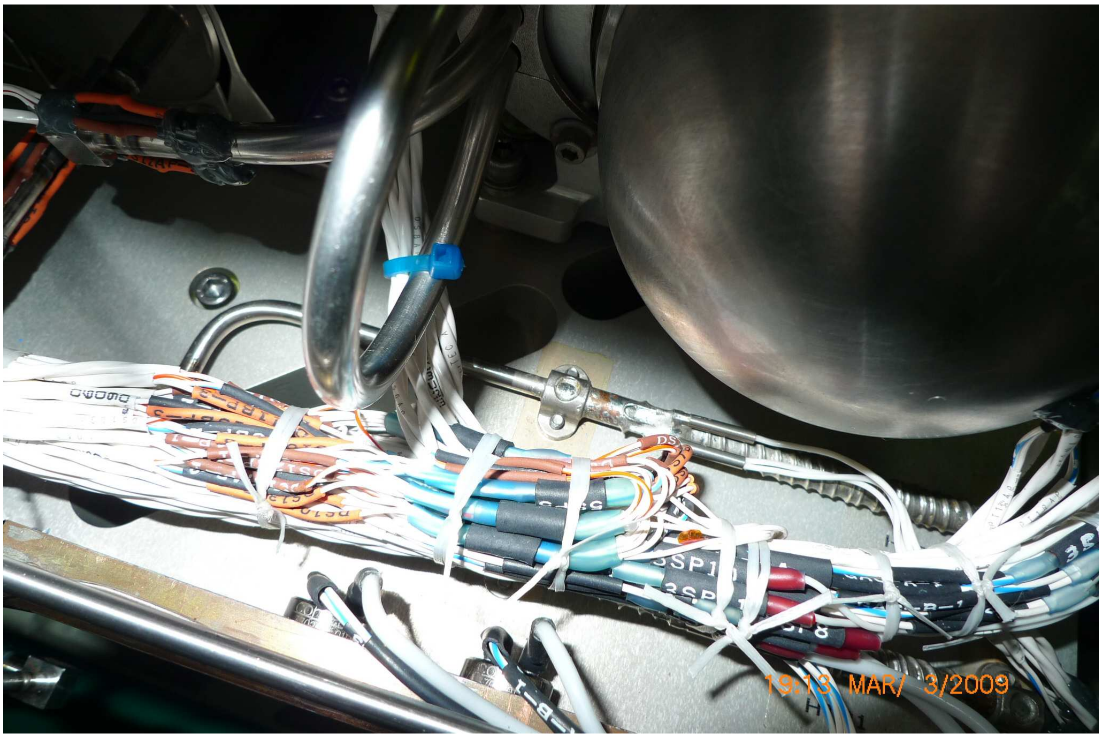


Figure 4-4: FM-Primary picture of the final flight assembly Primary box

4.1.2 Pre-heater electronic lay-out

In Figure 4-5 the TTCS heater schematic for the pre-heaters are shown.

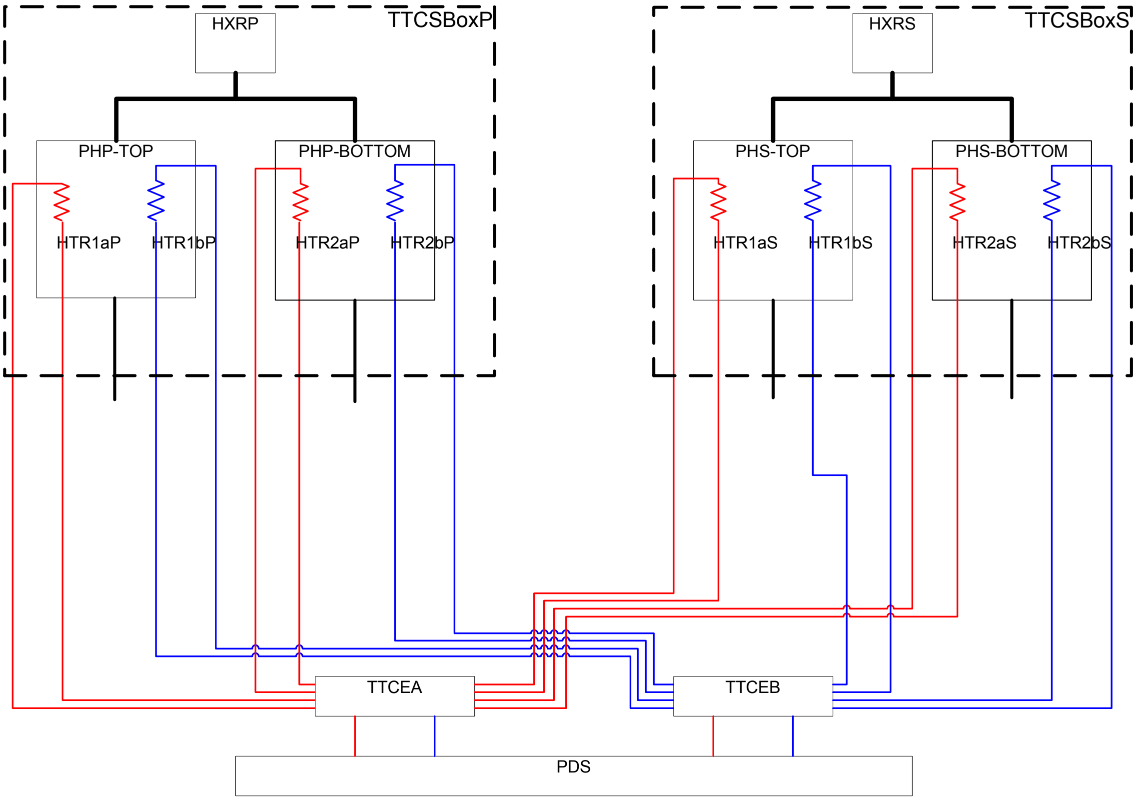


Figure 4-5: TTCS-boxes active components schematic with highlighted pre-heaters

Both boxes are shown. In each box the two branches are shown with the A and B heaters attached. The heaters are not protected with thermostats as the maximum temperature is acceptable for both the soldering connection and the pressure system requirement for this section (see RD-2).

4.1.3 Pre-heater specifications

The Pre-heater is a wire heater soldered onto the piping of the TTCS, the sizing of the wire heater is based on the minimal voltage of 26.5 Volts:

- P = 8.0 W
- R = 26.5^2/8.0 = 87.8 Ohm
- I_{nom} = 28/87.8 = 0.32 Ampere
- I_{max} = 29.5/8.0 = 0.34 Ampere (@ V_{max} = 29.5 Volts)
- P_{max} = 29.5^2/87.8 = 9.91 Watt
- L_{heater} = 87.8/330 = 0.266 m

Pre-Heater Id#	TTCE	Location	Function	Max Power @ 28 Vdc	Heater Type (Thermocoax)	Heater resistance (Ω)	Max Current at 29.5V (amps)	MaxPower density [Watt/m]
HTR1aP	A	P-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3
HTR2aP	A	P-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3
HTR1aS	A	S-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3
HTR2aS	A	S-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3
HTR1bP	B	P-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3
HTR2bP	B	P-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3
HTR1bS	B	S-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3
HTR2bS	B	S-box	Pre-heating	8.9	2NCNC D0.5 L0.266	87.8	0.34	37.3

Table 4-1: Pre-heater specifications

The heater is selected taking into account a maximum allowable power per unit of length (20 Watts/foot = 65.6 Watts/m):

- Thermo-coax 2NCNC D0.5 L0.266 (330 Ω/m)

The pre-heaters are directly soldered onto the liquid line:

- Material: Inconel
- Outer diameter: 0.5 mm
- Length: 0.266 m
- Power supply: 28.0 VDC (TTCE).

Requirements:

- The operational temperature –40 ˚C and 30 ˚C. (this is the temperature of the liquid)
- The non-operating temperature –60 ˚C and 160 ˚C
- Space qualified

The thermal analyses of the heater in operation mode and safety failure mode are presented in the safety approach document"AMSTR-NLR-TN-044-Issue01" [RD-2].

The connectors on each end of the wire heater are special Thermocoax connectors (CM05SPE/CEMENT8) and shown in Figure 4-6.

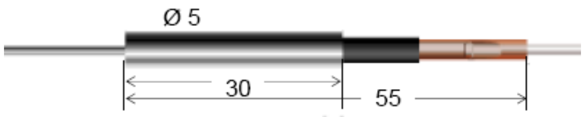


Figure 4-6: CM-05 Wire Heater Connector Layout

The CM05 connectors have the following specifications:

1. Maximum working temperature: 1000 °C for the cement 08 and the hot side of the wire heaters, 200 °C for the electrical wire.
2. The ceramic/metal connections can be used in vacuum (10^{-9} Bars).
3. Maximum allowable current 10 Ampere

4.2 Accumulator Heaters

The objective of the accumulator heaters is to keep accumulator (TTCS) at set-point in normal control conditions and to quick raise of accumulator set-point during off-nominal situations.

4.2.1 Accumulator heater location

The accumulator heaters can be divided in two types of heaters:

- Heaters attached to the accumulator heat pipe which will be used and connected to the TTCE in flight
- Heaters attached to the accumulator wall (mantle) only used for ground testing and NOT CONNECTED in flight

The accumulator location heater locations for the Secondary loop are indicated in Figure 4-7.

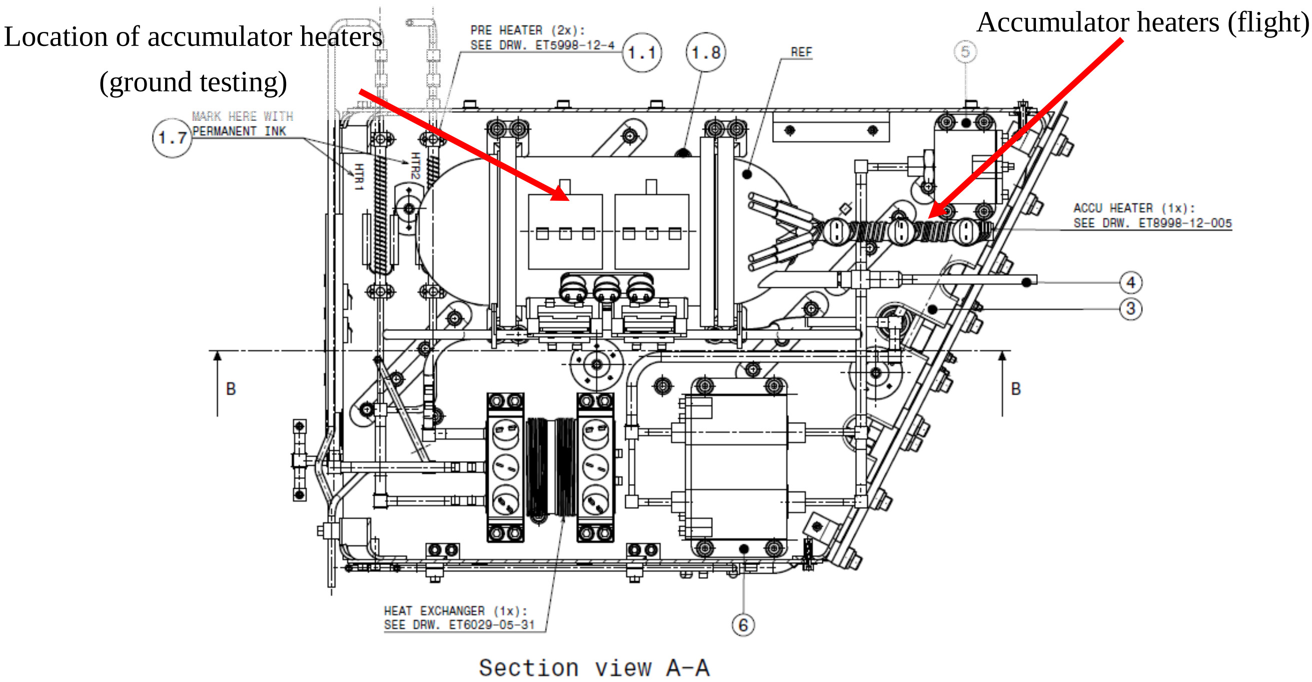


Figure 4-7: Location accumulator heaters

For the Secondary loop the ground test heater are located on the top of the accumulator to allow control of the accumulator also for low set-points (low accumulator levels) during the TV testing at ESTEC. At ESTEC the Secondary box is oriented upside down. The Primary loop is orientated normally and therefore the Primary ground test heaters are located at the bottom of the accumulator. The flight heaters are arranged in the same way for the Primary and Secondary loop.

The wire heaters will cover the complete HP outer surface. Two (2) heaters need to be accommodated.

4.2.2 Accumulator heaters electronics layout

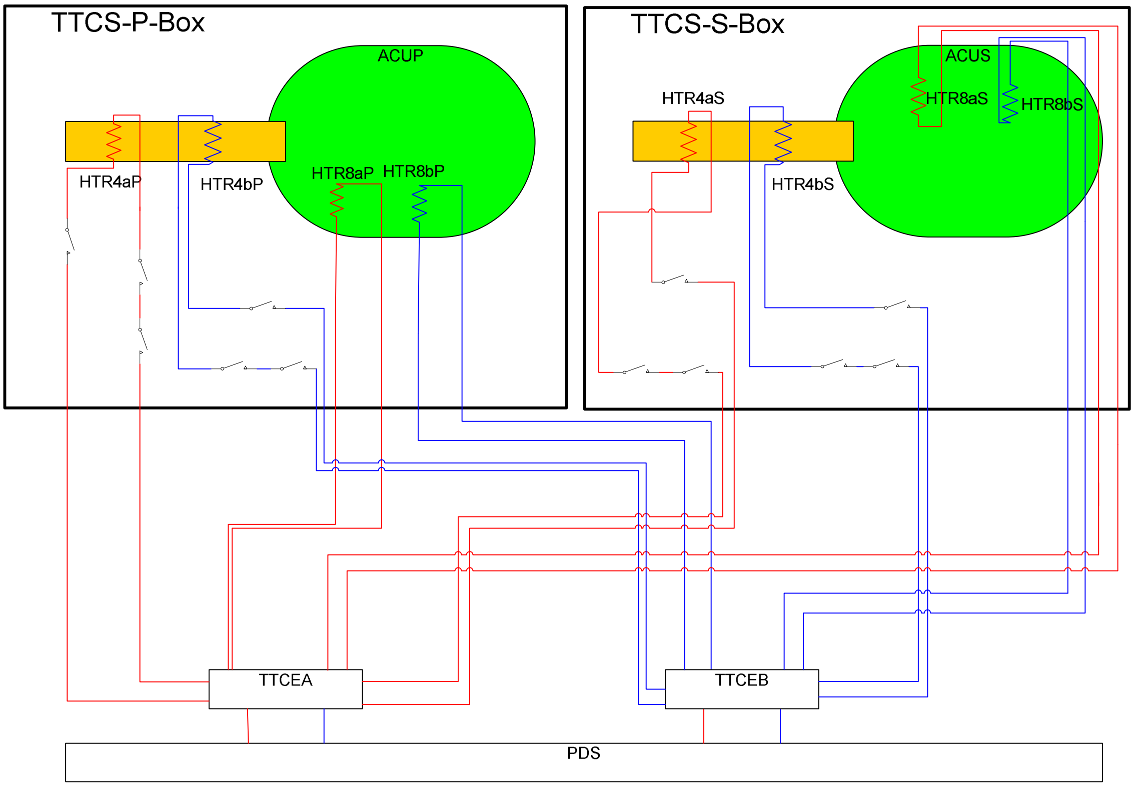


Figure 4-1: Accumulator heater schematic

The accumulator heater schematic for flight heaters (HTR4aP, HTR4bP, HTR4aS, HTR4bS) are shown located on the heat pipe (yellow pipe). The accumulator heaters for ground testing (HTR8aP, HTR8bP, HTR8aS, HTR8bS) are located on the accumulator vessel (green). In the accumulator flight heater schematics 3 heat switches are present. The ground test heaters will be protected by triple redundant Pt1000's for safety reasons during ground testing. These ground test heaters will be disconnected after ground testing and therefore not present during flight. The heater specifications are given in section 4.2.4.

4.2.3 Thermostat specification

The thermostats chosen for the accumulator are:

Comepa Model 45

Model 45

GAMT1
Automatic Reset

NFC 93450

SPECIFICATIONS

Electrical Rating

2A 125 VAC Resistive load
4A 30VAC Resistive load
1A 125VAC Inductive load
2A 30VAC Inductive load

Contact Resistance

≤50 mOhms

Dielectric Strengh

Contact and case 50 Hz ≥1000 V eff.
Open conctact 50 Hz ≥1000 V eff.

Heating Resistance

180 °C

Mechanical Strengh

Vibration 10 a 3000Hz 30g
Shocks 500g /1ms

Leakage rating

≤1.10-8 bar cm3/s

Switching durability

100000 times at rated load

The detailed specification of the thermostat set-points of all box thermostats is given in Appendix 07.

4.2.4 Accumulator heater specification

Accu-Heater Id#	TTCE	Location On Accumulator	Function	Nom Power @ 28 Vdc	Heater Type	Heater resistance (Ω)	Max Current @ 29.5 V	Power Density (Wire: W/m) (Foil: W/cm^2)
HTR4aP	A	Heat Pipe P-Box	Flight Control	37.5	Thermocoax 1 Hc Ac 10/746mm Connectors 2xCM10/E1419WHITE/200mm (AWG 14 wire)	20.9	41.63	55.75
HTR8aP	A	Accu Wall P-Box	Ground Test Control	40.2	Minco Foil Heater K5592 (With Minco PSA #10 Epoxy Adhesive) 44.5 mm x 44.5 mm, Type 21, 19.50 Ohm, 19.8 cm^2	19.50	44.6	2.25
HTR4bP	B	Heat Pipe P-Box	Flight Control	37.5	Thermocoax 1 Hc Ac 10/746mm Connectors 2xCM10/E1419WHITE/200mm (AWG 14 wire)	20.9	41.63	55.75
HTR8bP	B	Accu Wall P-Box	Ground Test Control	40.2	Minco Foil Heater K5592 (With Minco PSA #10 Epoxy Adhesive) 44.5 mm x 44.5 mm, Type 21, 19.50 Ohm, 19.8 cm^2	19.50	44.6	2.25
HTR4aS	A	Heat Pipe S-Box	Flight Control	37.5	Thermocoax 1 Hc Ac 10/746mm Connectors 2xCM10/E1419WHITE/200mm (AWG 14 wire)	20.9	41.63	55.75
HTR8aS	A	Accu Wall S-Box	Ground Test Control	40.2	Minco Foil Heater K5592 (With Minco PSA #10 Epoxy Adhesive) 44.5 mm x 44.5 mm, Type 21, 19.50 Ohm, 19.8 cm^2	19.50	44.6	2.25
HTR4bS	B	Heat Pipe S-Box	Flight Control	37.5	Thermocoax 1 Hc Ac 10/746mm Connectors 2xCM10/E1419WHITE/200mm (AWG 14 wire)	20.9	41.63	55.75
HTR8bS	B	Accu Wall S-Box	Ground Test Control	40.2	Minco Foil Heater K5592 (With Minco PSA #10 Epoxy Adhesive) 44.5 mm x 44.5 mm, Type 21, 19.50 Ohm, 19.8 cm^2	19.50	44.6	2.25

Table 4-2: Accumulator heater table (yellow flight heaters, green ground testing heaters)

4.2.4.1 Accumulator control heaters details

Function: Regulate evaporation set-point in all operational modes (heating).
Location: The Accumulator control heaters will be placed on the heat pipe. A wire heater with stainless steel is chosen since the accumulator heat pipe is made of stainless steel.

The accumulator heaters are sized such that the required power 37.5 W is delivered with 100% duty cycle @ 28.0 VDC.

The heat pipe on the accumulator will be equipped with a wire heater:

- P = 37.5 W
- R = $28^2/37.5$ = 20.9 Ohm
- I_{nom} = 28/20.9 = 1.34 Ampere
- I_{max} = 29.5/20.9 = 1.41 Ampere (@ V_{max} = 29.5 Volts)
- L_{heater} = 746 mm

The selected elements are the 1NcAc wire heaters of THERMOCOAX (www.thermocoax.com) with stainless steel sheath. Thermocoax 1 Hc Ac 10 mm diameter with 746mm lenght.
The 1NcAc wires have a power output per unit length of **28 ohms/m.** This results in following approximated length:

R=34.84 ohm ==========> L1 = 746 mm

In the table below information is listed about the wire:

	Accu control wire heater
Coating material	Stainless steel 304L
Diameter	1.0 mm
Length Cold Parts	No cold ends
Length Hot Part	746 mm
Resistance (High Temp)	20.9 Ohm
Nominal Power supply	28 Volt
Power (approx)	37.5 Watt
Connector type	Connectors 2xCM10

Table 4-3: Accumulator control heater wire details

The connectors on each end of the wire heater are standard Thermocoax connectors CM10 are shown in Figure 4-2.

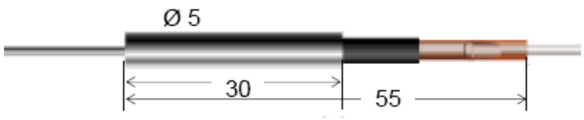


Figure 4-2: CM-10 Wire Heater Connector Layout

The CM10 connectors have the following specifications:

1. Maximum working temperature: 200 °C for the CM10 and the hot side of the wire heaters, also 200 °C for the electrical wire.
2. The ceramic/metal connections can be used in vacuum (10^{-9} Bars).
3. Maximum allowable current 10 Ampere

The thermocoax ordering code for the accumulator control heaters is Thermocoax 1 Hc Ac 10/746mm Connectors 2xCM10/E1419WHITE/200mm (AWG 14 wire).

As stated before the wire heaters are soldered onto the accumulator heat pipes, this can be seen in Figure 4-9. The heater connectors are located at one side of the heat pipe. This is possible because the minimum bending radius of the wires is 3 mm (3 times the wire outer diameter), making it possible to mount the wires onto the heat pipe in the configuration seen in Figure 4-9.

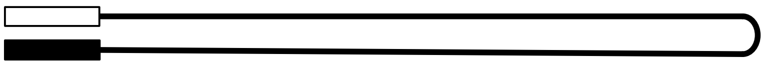


Figure 4-8: Accumulator heaters sconfiguration

The power lines (Feed and Return lines) are soldered onto the connectors ends.

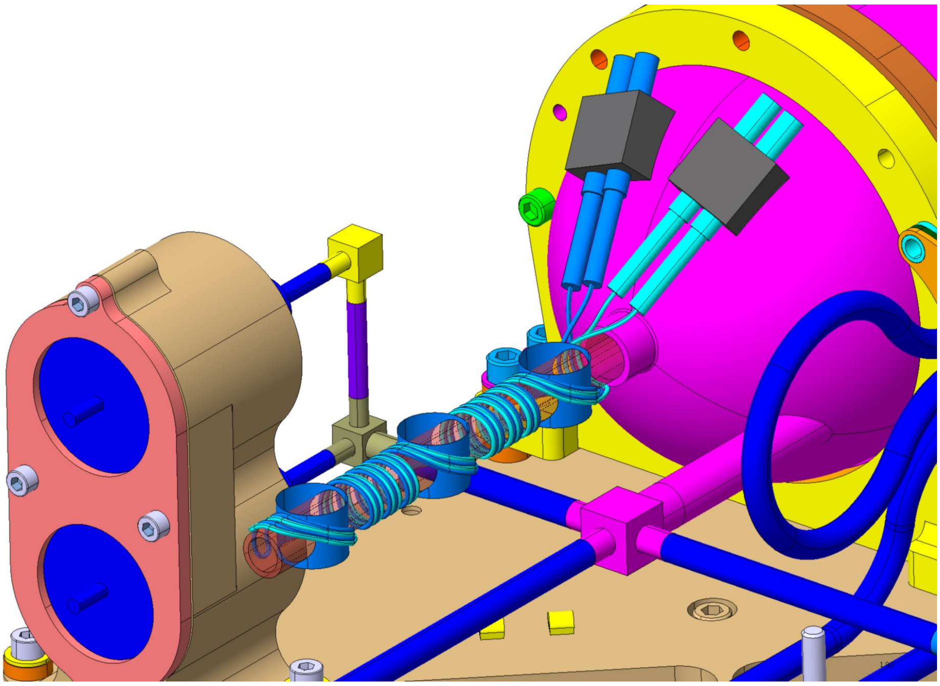


Figure 4-9: 3D view of the accumulator flight heaters placement onto the accumulator heat pipe

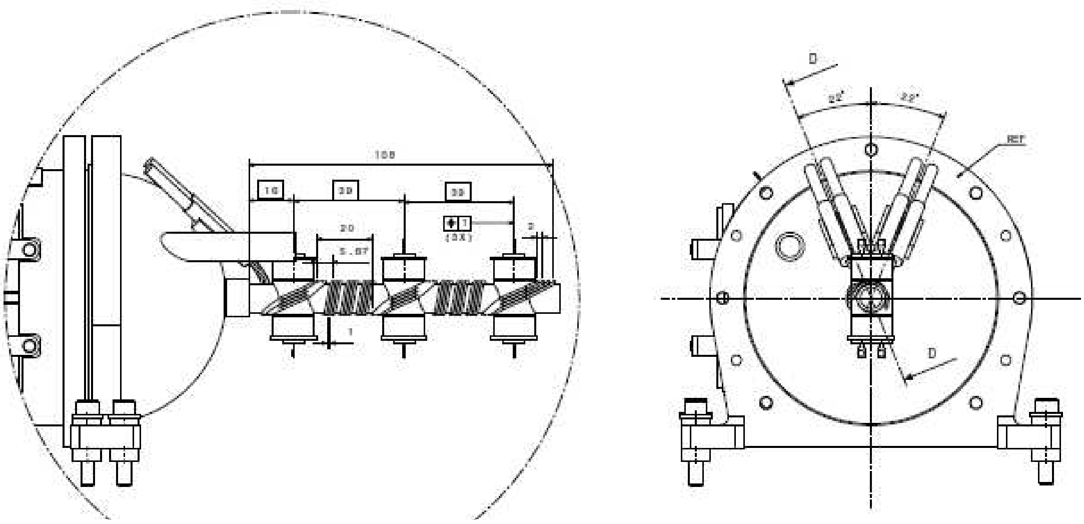


Figure 4-10: Accumulator detailed drawing of wire heaters placement on heat pipe

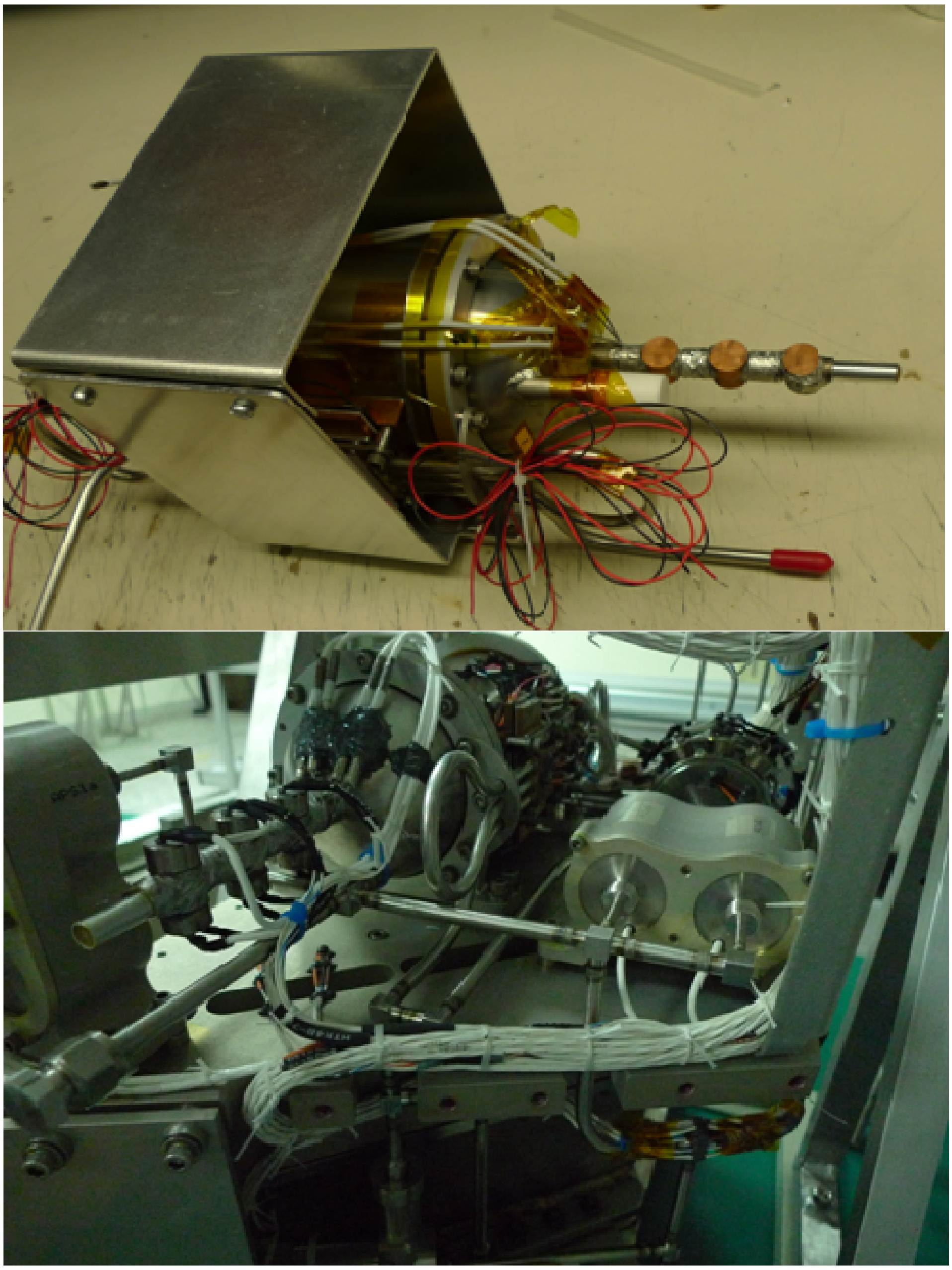


Figure 4-11: Picture of the implemented accumulator wire heaters

4.2.4.2 Accumulator ground test heaters details (in TTCS boxes)

Function: The ground test heaters have the same function and power output as the accumulator control and emergency heaters.

Location: Directly on the accumulator wall.

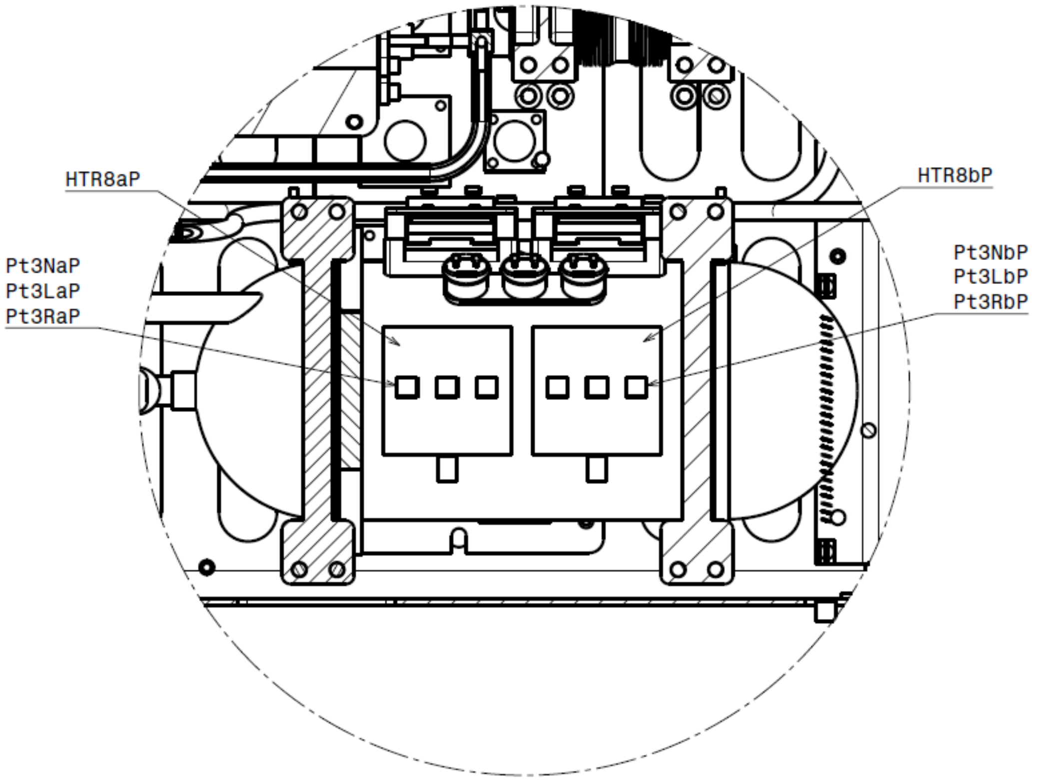


Figure 4-12: Accumulator ground control heater located on the TTCS accumulator wall

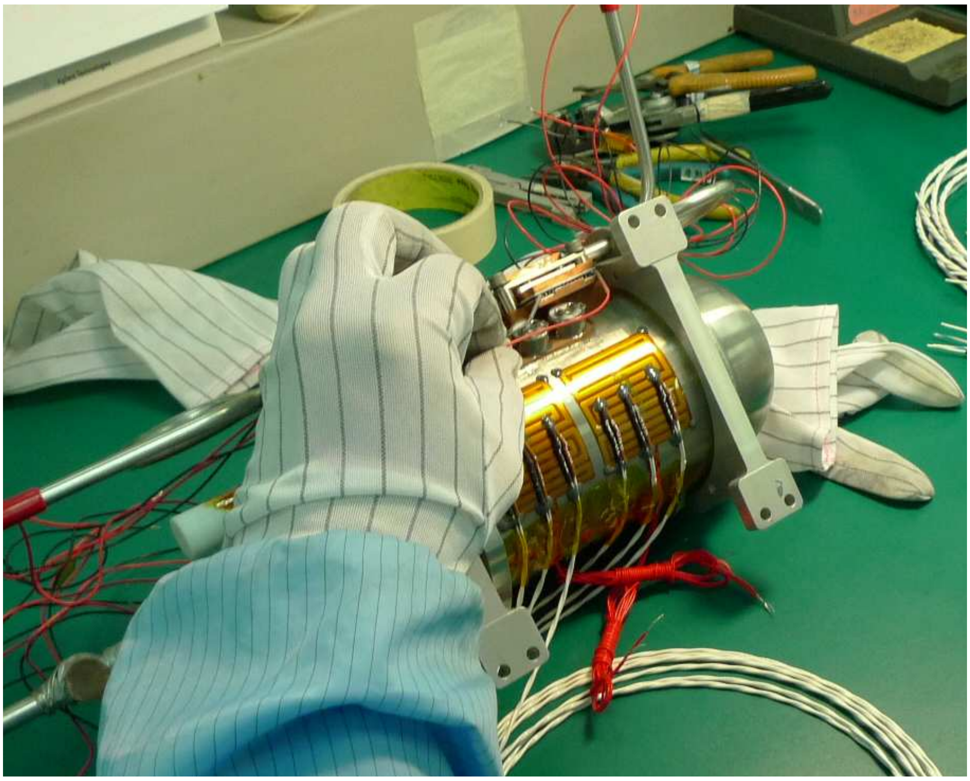


Figure 4-13: Accumulator ground control heater located on the TTCS accumulator wall

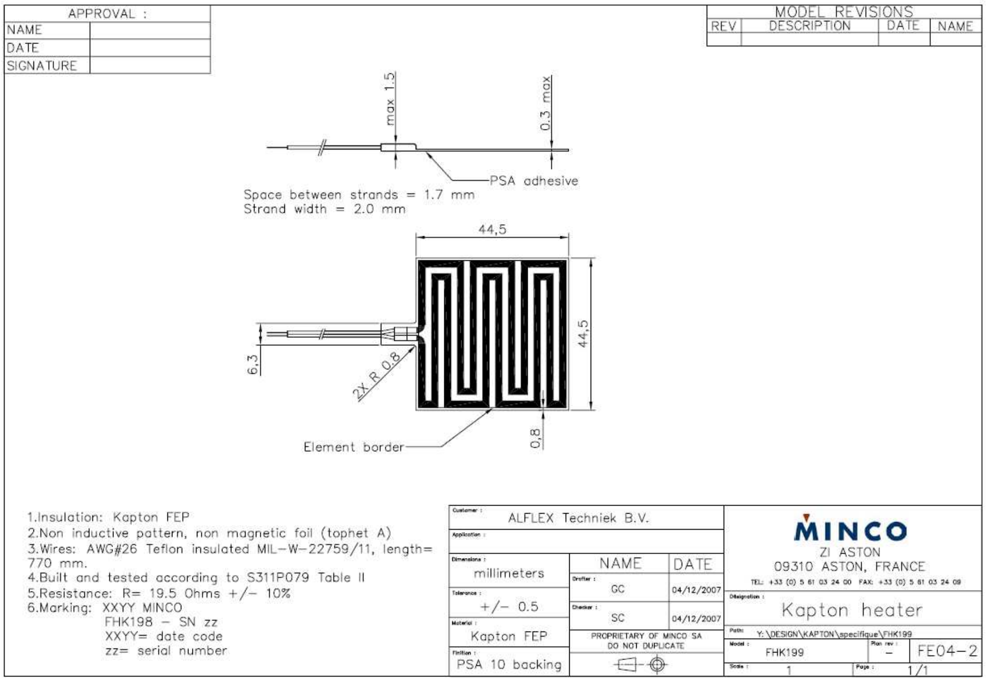


Figure 4-14: Accumulator ground heater specification

The accumulator ground test heaters have a maximum power density of respectively 2.54 and 2.07 [W/cm^2] for the control and emergency ground test heaters. This is above the flight requirement for foil heaters of 0.456 [W/cm^2]. The ground test heaters are disconnected from the power line before flight and thus this power density requirement is not applicable for the ground test heaters. The procedure for inhibiting operation of the ground test heaters during flight is outlined in the safety approach document:"AMSTR-NLR-TN-044-Issue01" [RD-2].
During ground testing in the Large Space Simulator (LSS) the accumulator temperature will be monitored by triple redundant Pt1000's Pt1 to avoid overheating of the accumulator. The heater temperature will be monitored by triple redundant Pt1000's Pt3.

4.3 Start-up heaters (in TTCS boxes)

The objective of the start-up heaters is to raise the TTCS liquid flow from – 40 °C to – 20 °C during start-up and cold orbit operation.

4.3.1 Start-up heater location

The start-up heaters are located on the heat exchanger in the TTCS boxes as indicated in Figure 4-15.

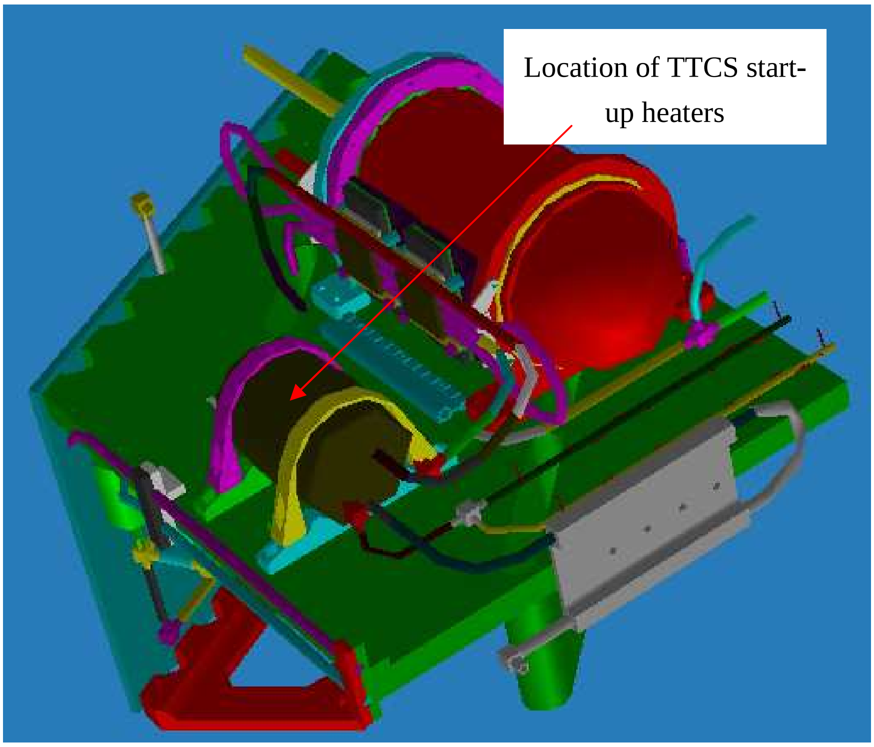


Figure 4-15: Start-up heater location

The start-up heaters are wire heaters soldered to the large thermal mass of the TTCS heat exchanger.

4.3.2 Start-up heater electronics lay-out

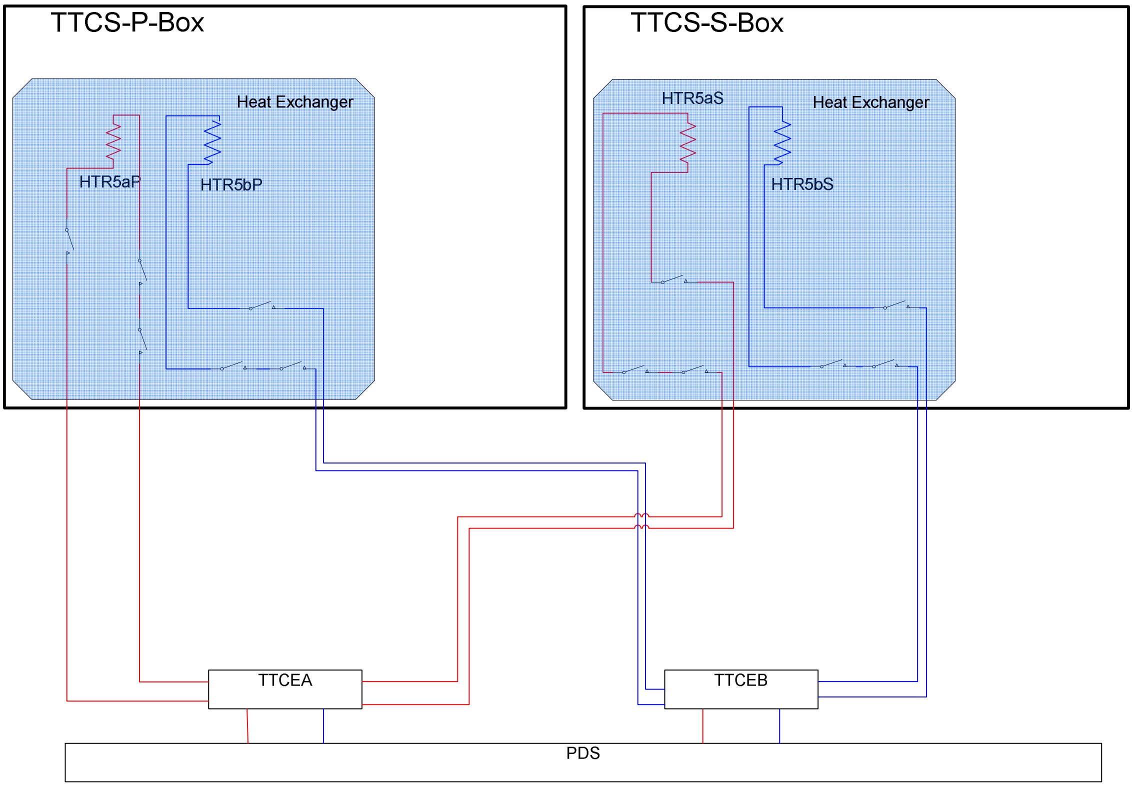


Figure 4-16: Start-up heater schematic

The start-up heaters (HTR5aP, HTR5bP) are shown in red (a) and blue (b) for the Primary box. The start-up heaters (HTR5aS, HTR5bS) can be found in the left side . The heaters are connected to the TTCE-box. The heaters are redundant. The start-up heaters are protected by 3 thermal switches in series for safety reasons.The thermostats are located on the upper bracket as seen in Figure 4-17. The fault heater analysis is presented in the TTCS document "*AMSTR-NLR-TN-044_1.0_TTCS_Safety_Approach.doc*".

The thermostats chosen are the same type as for the accumulator heaters, seen section 4.2.2. The

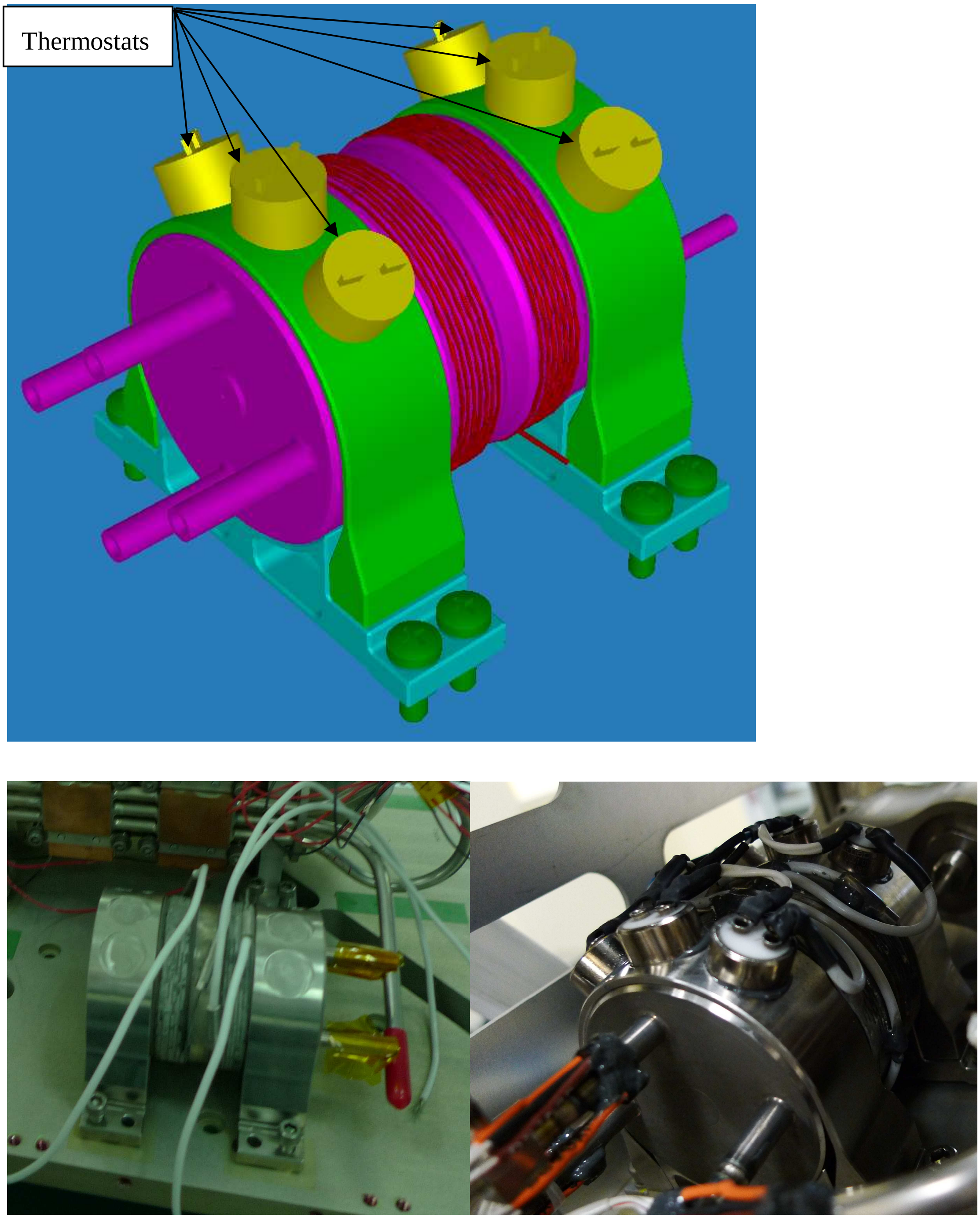


Figure 4-17: Thermostat and wire heaters placement onto the TTCS heat exchanger

4.3.3 Start-up heater specifications

The start-up heaters are placed on the heat exchanger. Wire heaters are chosen because:

- The maximum surface available on the heat exchanger (A = 111 cm^2).
- The maximum power density allowable for foil heaters (0.465 W/cm2).

Each heat exchanger will be equipped with two redundant wire heaters. The heaters are sized such that they deliver a power of 50 Watt @ the nominal voltage of 28.0 VDC. The heater is selected taking into account the maximum allowable power per unit of length (20 Watts/foot = 65.6 Watts/m):

- P = 50 W
- R = $28^2/50$ = 16.0 Ohm
- I_{nom} = 28/16.0 = 1.75 Ampere
- P_{nom} = $28^2/16.0$ = 50 Watt
- I_{max} = 29.5/16.0 = 1.84 Ampere
- L_{heater} = 16.0/12.5 = 1.25 m

The selected elements are the THERMOCOAX ZEZI wire heaters (www.thermocoax.com).
Wire heater ZEZI10/8-128-8/2xCM10/CEMENT8/E1419WHITE/200mm (AWG 14 wire)
This is a single core wire heater with cold ends. The wire chosen has a sheath metal of Inconel.
The ZEZI wires have a line resistance per unit length of 12.5 **ohms/m.** This results in following approximated hot length:

R=16 Ohm ==========> L1 = 128 cm

In the table below information is listed about the wire:

	Start-up wire heater
Coating material	Inconel alloy 600
Diameter	1.0 mm
Length Cold Parts	10 cm (on each end)
Length Hot Part	128 cm
Total length	148 cm
Resistance (High Temp)	12.5 Ohm/m
Nominal Power supply	28.0 Volt
Power (approx @ 28.0 Volts)	50.0 Watt
Power density @ 29.5 V	42 Watt/m
Connector type	CM10/CEMENT8

Table 4-4: Start-up heater specifications

With the above chosen wire heater the wire heater will be soldered on the heat exchanger and will have 7.3 turns around the heat exchanger.

The connectors on each end of the wire heater are standard Thermocoax connectors (CM10/CEMENT8) are shown in Figure 4-18.

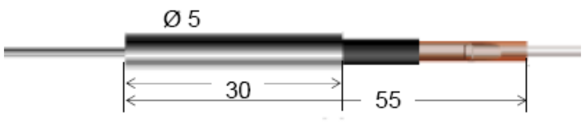


Figure 4-18: CM-10 Wire Heater Connector Layout

The CM10 connectors have the following specifications:

1. Maximum working temperature: 1000 °C for the cement 08 and the hot side of the wire heaters, 200 °C for the electrical wire.
2. The ceramic/metal connections can be used in vacuum (10^{-9} Bars).
3. Maximum allowable current 10 Ampere

Detailed description (Technical information) on the Cement8 connector is to be found in **Appendix 04 and 05.**

4.4 Cold Orbit Heaters (in TTCS boxes)

The objective of the cold-orbit heaters is to raise the CO2 temperature to such a temperature that freezing is prevented in the condenser during cold orbits.

4.4.1 Cold orbit heaters location

The cold orbit heaters are located in the TTCS-boxes after the exit of the heat exchanger and before the split into the Wake and Ram condenser feed lines. (See Figure 3-1 and Figure 3-2). The cold orbit section will be located directly on the TTCS base-plate. The location of the cold orbit heater in the box is seen in Figure 4-19.

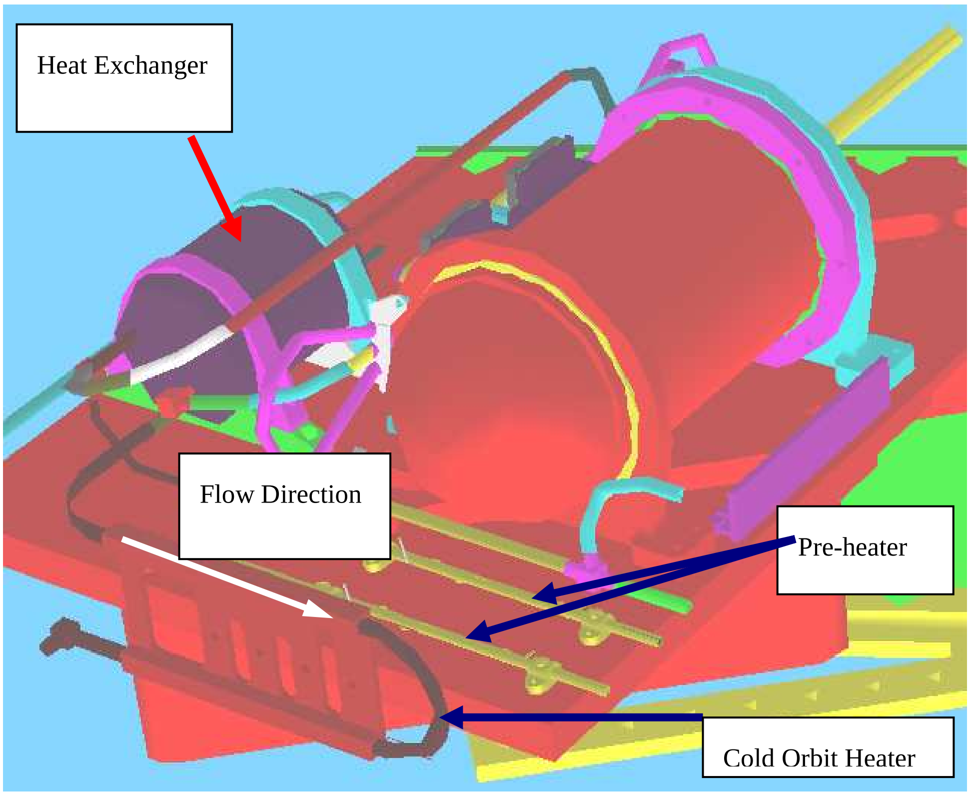


Figure 4-19: Cold Orbit heater location on the base-plate

The cold orbit consists of a copper structure of approx. 5 cm by 11.5 cm. The liquid line from the heat exchanger to the radiators is soldered to this copper structure along the wire heaters.
The model the cold-orbit heater is shown in Figure 4-20. The detailed design can be found in Appendix 11.

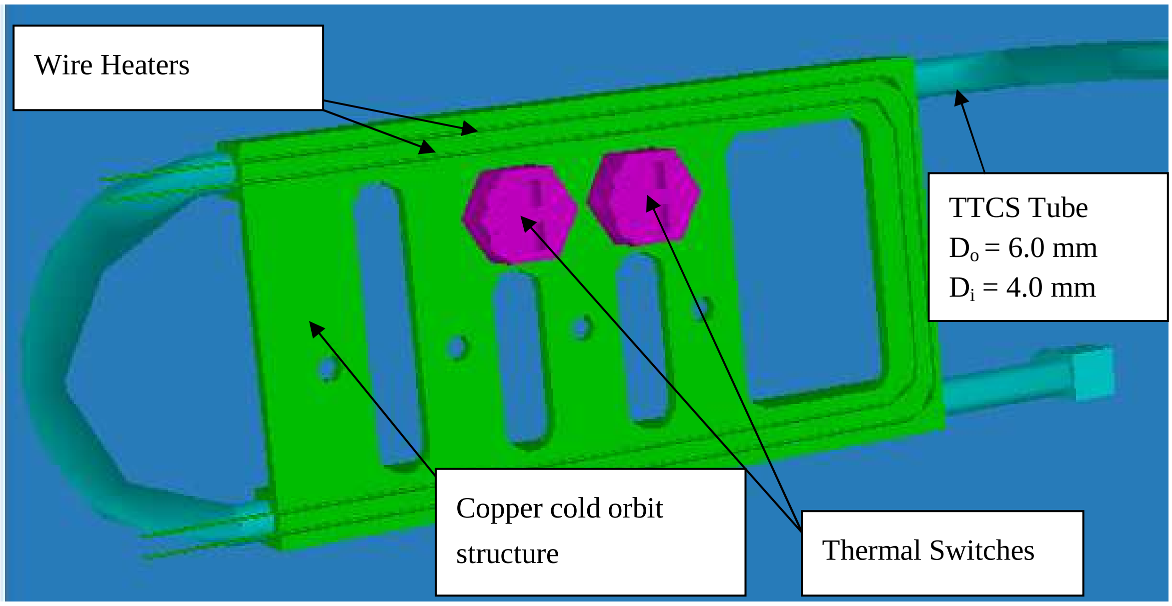


Figure 4-20: Cold Orbit Heater model and detailed design

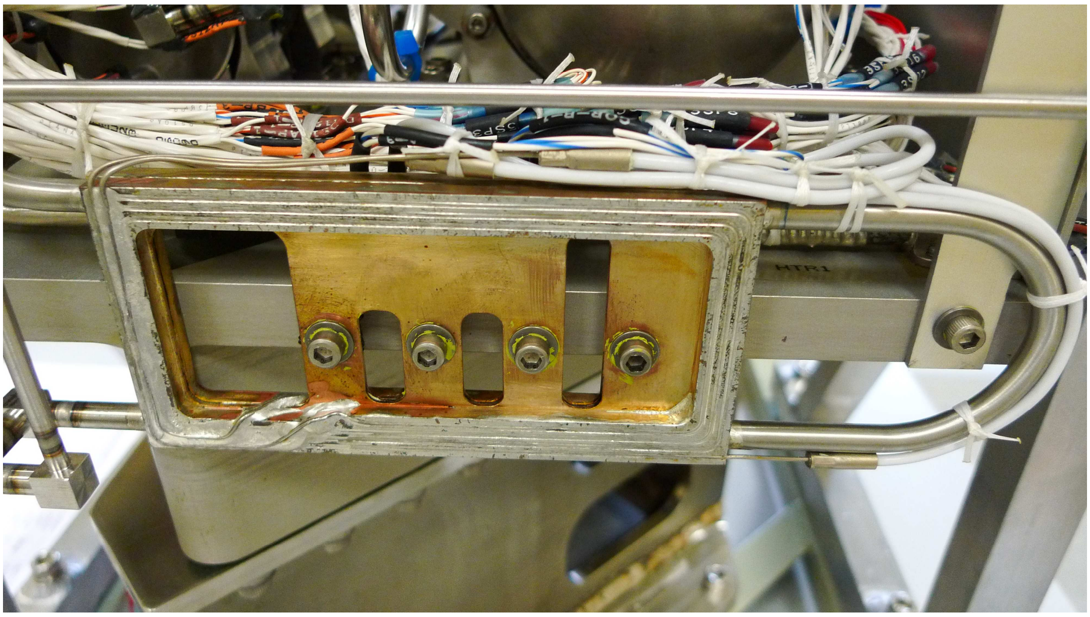


Figure 4-21: Integrated cold orbit heater

For mission success reasons one thermal switch per heater is installed to avoid overheating of the solder in case of a switched on heater with a non-running loop.

The safety approach and the maximum temperature @ heater/thermostat failure are presented in the TTCS safety approach document "*AMSTR-NLR-TN- 4_1.0_TTCS_Safety_Approach.doc*".

The thermostats chosen are the same as the accumulator thermostats seen in section 4.2.2.

4.4.2 Cold Orbit Heaters electronic lay-out

In Figure 4-22 the TTCS heater schematic for the pre-heaters are shown.

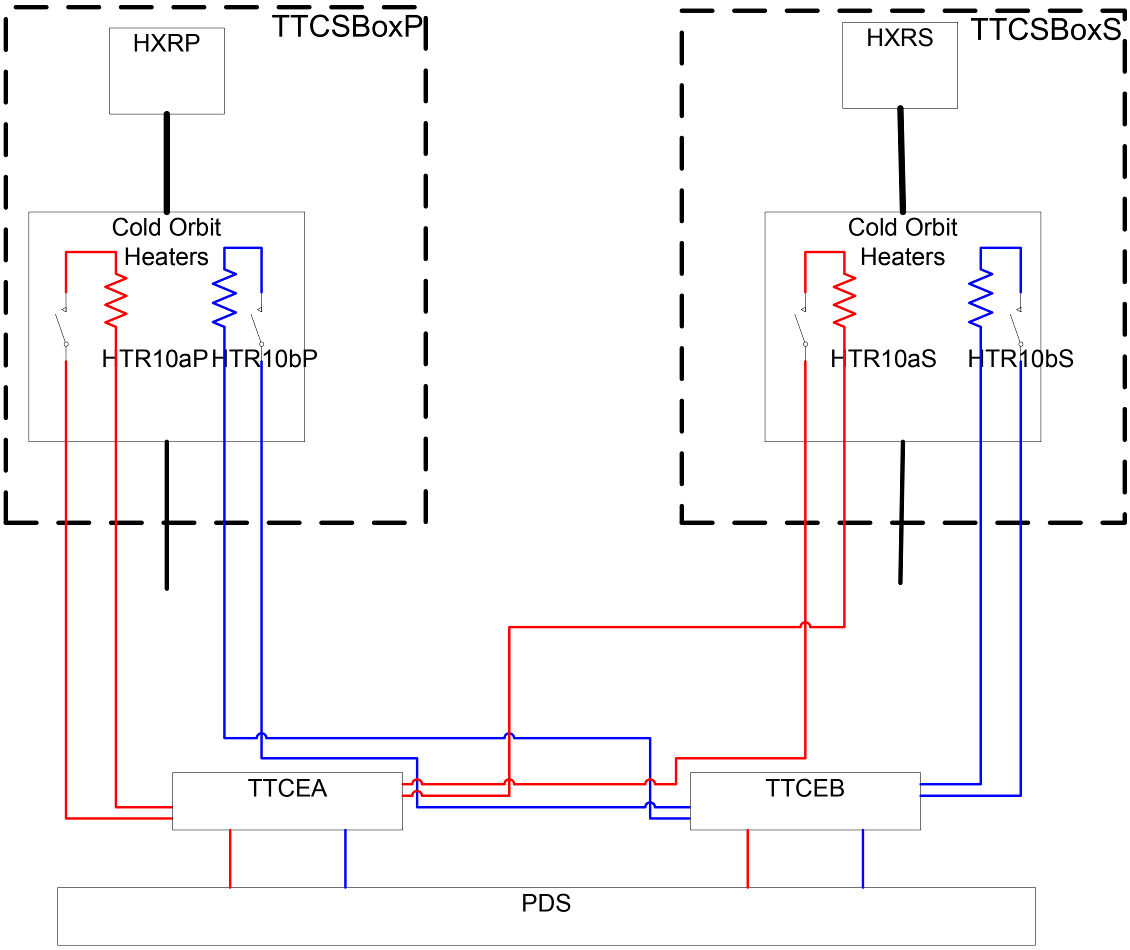


Figure 4-22: TTCS-boxes active components schematic Cold Orbit Heaters

Both boxes are shown with the A and B heaters attached.

4.4.3 Cold Orbit Heater specifications

The heater is selected taking into account the maximum allowable power per unit of length (20 Watts/foot = 65.6 Watts/m):

- P = 60 W
- R = 28^2/60 = 13.07 Ohm
- I_{nom} = 28/15.7 = 2.14 Ampere (@ 28.0 Volts)
- I_{max} = 29.5/15.7 = 2.25 Ampere (@ 29.5 volts)
- L_{heater} = 13.07/12.5 = 104.5 cm

The selected elements are the ZEZ wire heaters of THERMOCOAX (www.thermocoax.com). The ZEZAc wires have a power output per unit length of **12.5 ohms/m.** This results in following approximated length:

R=13.7 ohm ==========>   L1 = 104.5 cm

In the table below information is listed about the wire as delivered by the manufacturer:

	Cold Orbit wire heater
Coating material	RVS 304
Diameter	1.0 mm
Length Cold Parts	0 (Variable)
Length Hot Part	104.4 cm
Resistance (High Temp)	13.07 Ohm
Power supply	28 Volt
Nom Power (@28.0 Volts)	60 Watt
Power Density @ 29.5 V	63.7 Watt/m
Connector type	CM10/CEMENT8

Table 4-1: Cold Orbit heater specifications

Heater Id#	TTCE	Location	Function	Nominal Power @28Vdc [Watt]	Heater Type (Thermocoax)	Heater resistance [Ω]	Power Density @29.5 V [W/m]	Max current @ 29.5 [Amp]
HTR10aP	A	P-Box	Cold Orbit Heater	60	ZEZAcD1.0 L1.04	13.07	63.7	2.25
HTR10aS	A	S-Box	Cold Orbit Heater	60	ZEZAcD1.0 L1.04	13.07	63.7	2.25
HTR10bS	B	P-Box	Cold Orbit Heater	60	ZEZAcD1.0 L1.04	13.07	63.7	2.25
HTR10bS	B	S-Box	Cold Orbit Heater	60	ZEZAcD1.0 L1.04	13.07	63.7	2.25

Table 4-5: Cold Orbit Heater specifications

The wire heaters are soldered onto the cold orbit copper structure as seen in Table 4-5. The heater is selected taking into account a maximum allowable power per unit of length (20 Watts/foot = 65.6 Watts/m):

- Thermo-coax ZEZAc D1.0 L1.04 (12.5 Ω/m)

4.5 TTCS liquid line health heaters

The objective of the TTCS liquid line heaters is to defrost the TTCS CO2 condenser lines after an AMS complete power down. The TTCS liquid line heaters are connected to the TTCE and operate at 28 V.

Important remark: The liquid line heaters should be switched on before the 120 V defrost heaters of the Tracker radiators itself (see section 5). The liquid lines need to be unfrozen before the condenser section starts to be defrosted. This in order to avoid high pressures in the condenser sections. Safety is looked after by the radiator heater thermostats so it is not a safety issue but a matter of common sense not to stress the condenser lines if not needed.

4.5.1 TTCS liquid line health heater locations

The TTCS liquid line heaters are located near both the RAM and WAKE Tracker radiators. The heaters location is shown in yellow in Figure 4-23. The heaters are connected to the TTCS primary and secondary condensers tubing running from the USS Upper Vacuum Case joints to the Tracker radiator condensers. A total of four (4) condensers are present. The Primary condensers are located at the Port side of AMS Tracker radiators and the Secondary condensers are located at the Starboard side of AMS.

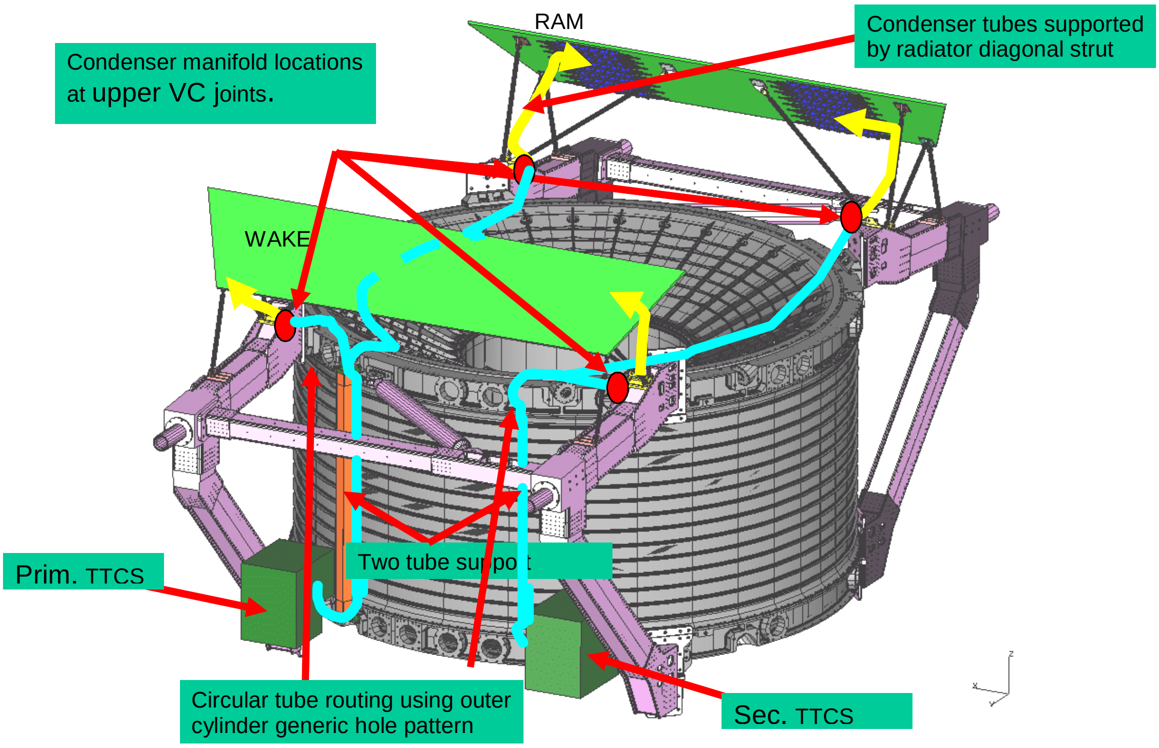


Figure 4-23: Location of the TTCS liquid line heaters (yellow)

The condenser tubing for each of the 4 condensers consists of 14 parallel Inconel tubes (7 inlet and 7 exit tubes). This is shown in Figure 4-24. Two (2) heaters are wrapped around 14 parallel condenser tubes (Figure 4-24). One additional heater is located at the inlet/outlet of the condenser plate to cover the heat leak to the condenser.

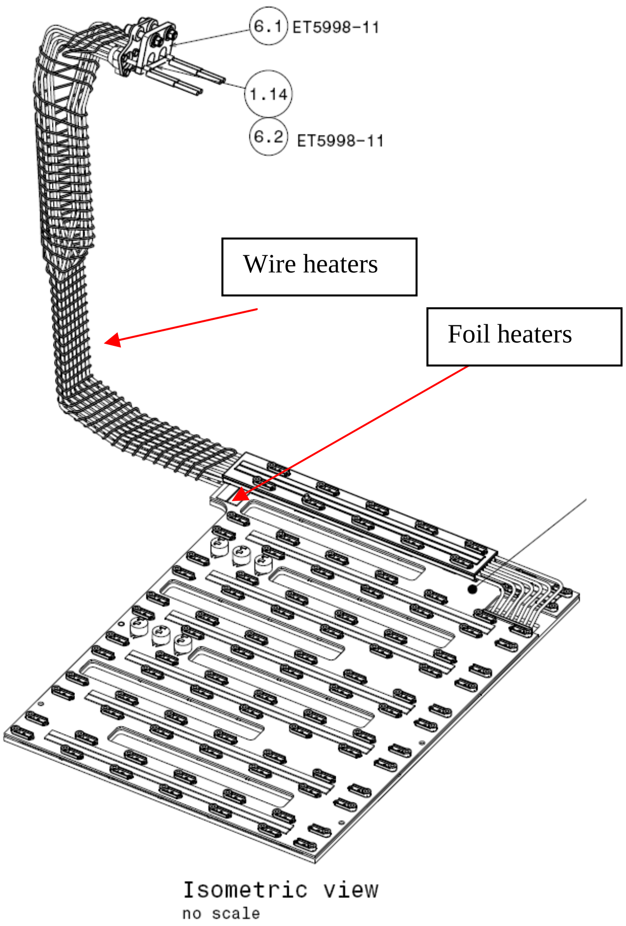


Figure 4-24: TTCS liquid line heater design Primary Wake and Secondary RAM

The heaters are not rigidly attached to the condenser lines but wrapped around. The heater is used to heat the volume including the condenser tubes. Therefore Multi Layer Insulation (MLI) is placed around the capillary tubes. In Figure 4-25 a schematic drawing of the layout is seen. Around the condenser tube bundles two wire heaters are wrapped. One powered by TTCE-A and one by TTCE-B.

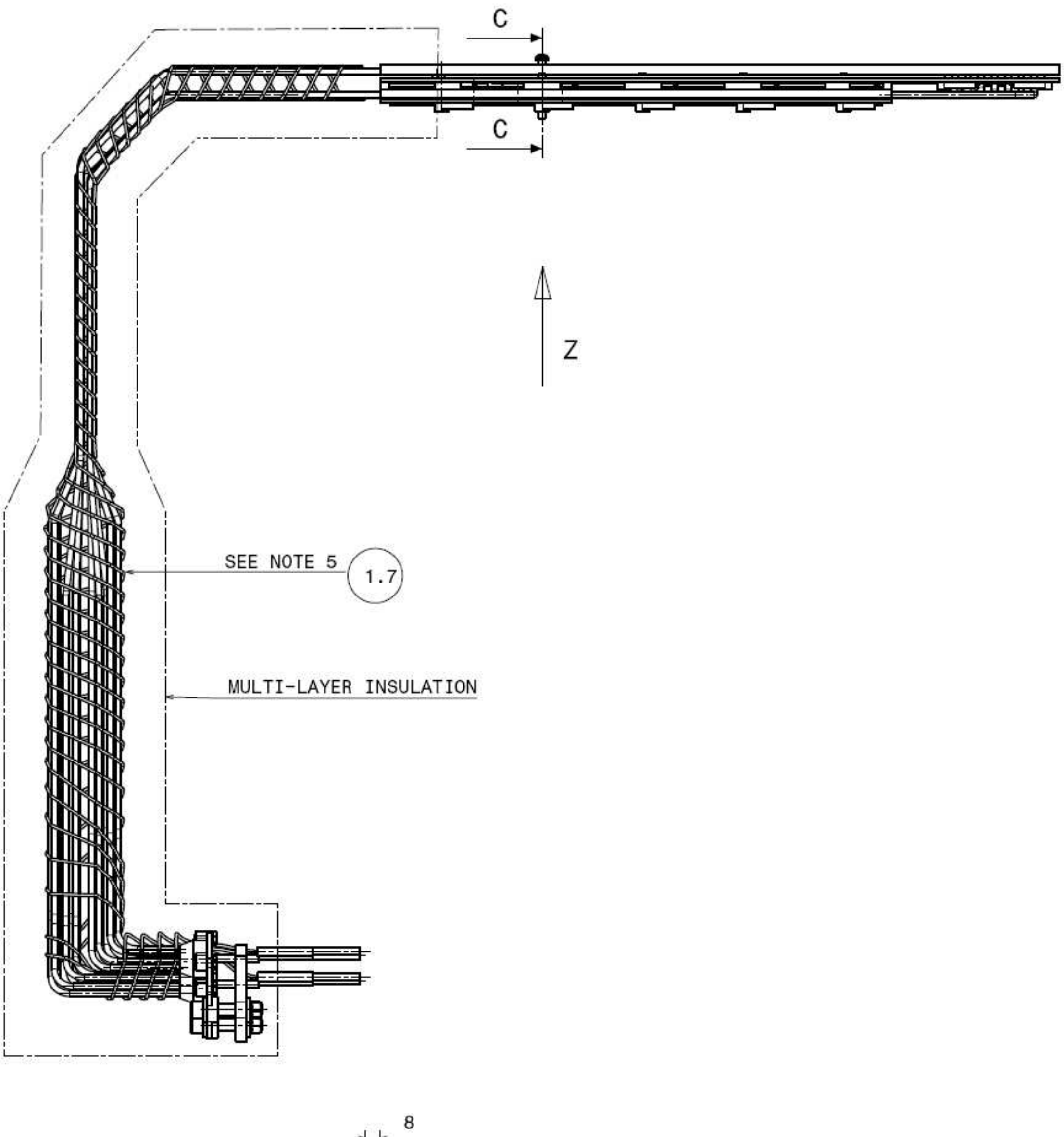


Figure 4-25: MLI heater insulation of the Primary wake and Secondary RAM condenser

The dimensions of the liquid capillary lines are: D_{in} = 1.0 mm, D_{out} = 3.15 mm, L = 0.70 m inlet and L = 0.70 m outlet.

The Minco Foil Heater on the condenser plate is placed in series with the wire heater wrapped around the condenser lines. The heater is located entrance of the capillary liquid lines into the condenser. This is done to compensate the heat leak from the liquid lines into the cold condenser at freezing. The location of the foil heater is seen in the figure above and in more detail below.

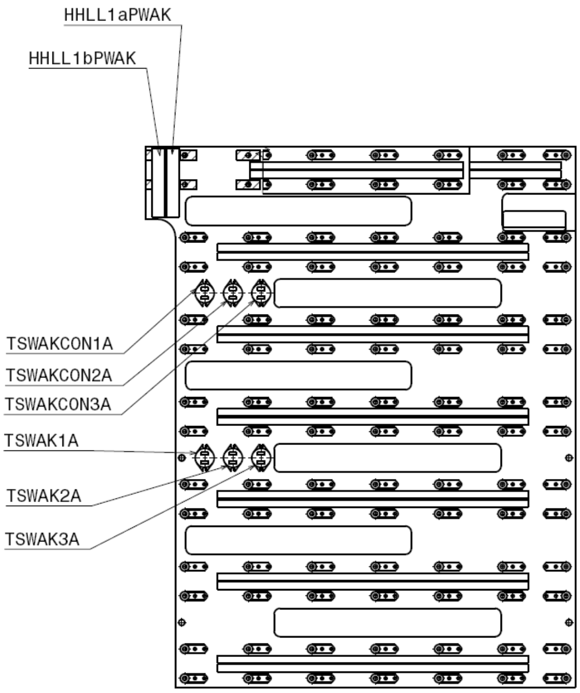


Figure 4-26: Location of the additional TTCS liquid line heater.

The heaters wrapped onto the capillary liquid such that both the feed and return lines terminal blocks are located near the manifold. This is achieved by double folding the wire heaters before wrapping it around the capillary liquid lines; this is seen in Figure 4-27.

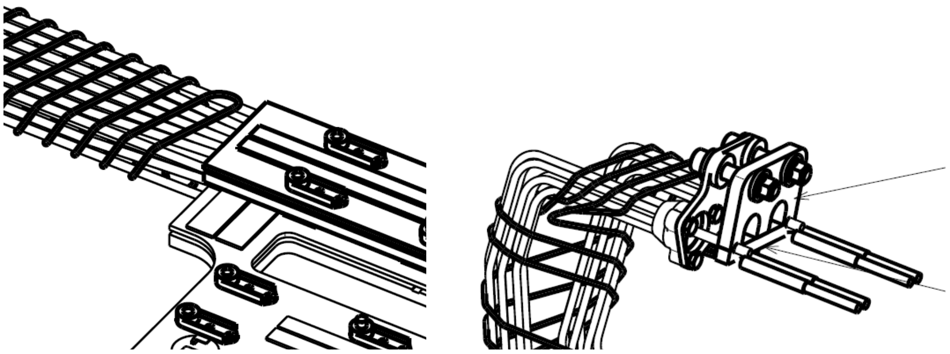


Figure 4-27: Heater assembly on capillary liquid lines (details).

4.5.2 Liquid line heaters electronic lay-out

The lay-out of the electronics is shown in Figure 4-28 to Figure 4-31.

All four condensers have the same heater lay-out and each are individually connected to the TTCE-A and TTCE-B. It is proposed to have only one on/off control for all liquid line heaters.

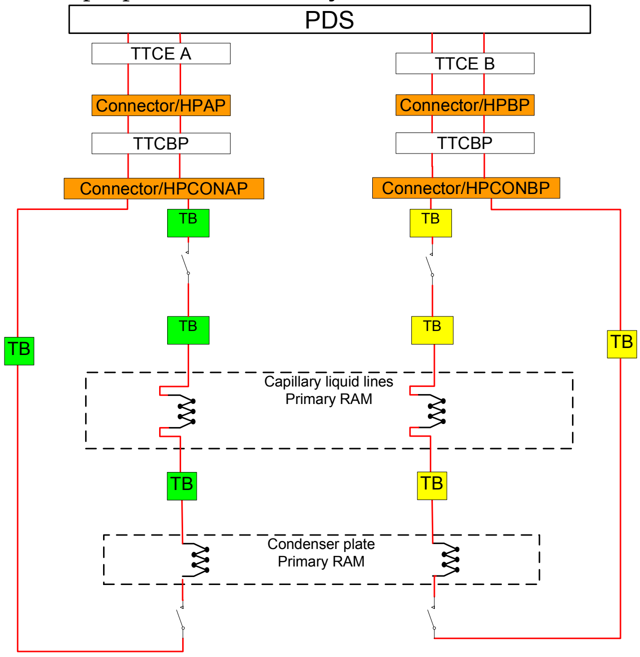


Figure 4-28: TTCS RAM Liquid line heaters schematic primary condenser

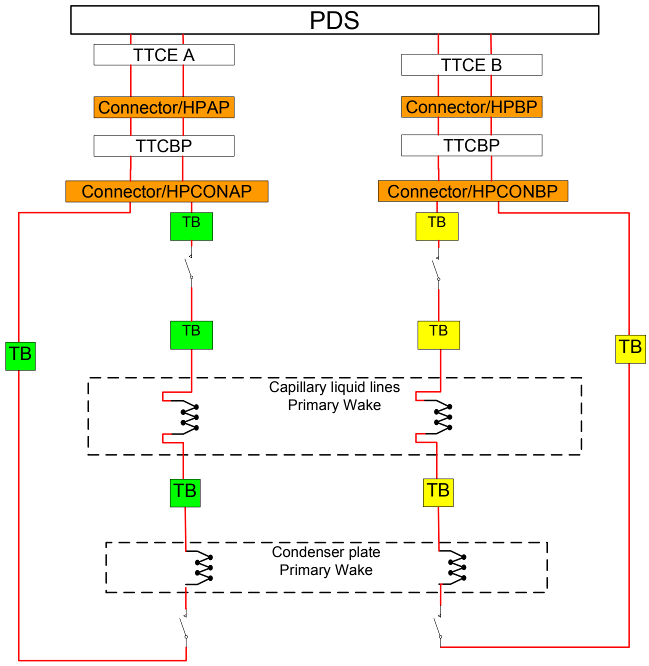


Figure 4-29: TTCS Wake Liquid line heaters schematic primary condenser

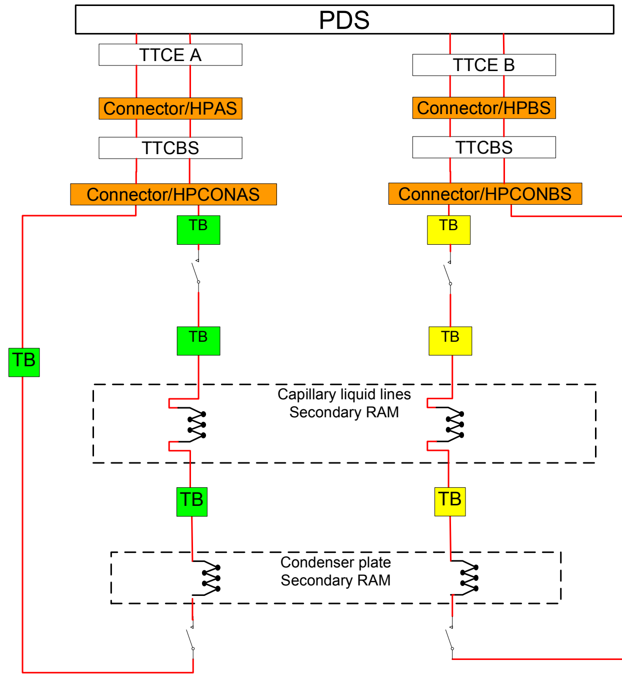


Figure 4-30: TTCS RAM Liquid line heaters schematic secondary condenser

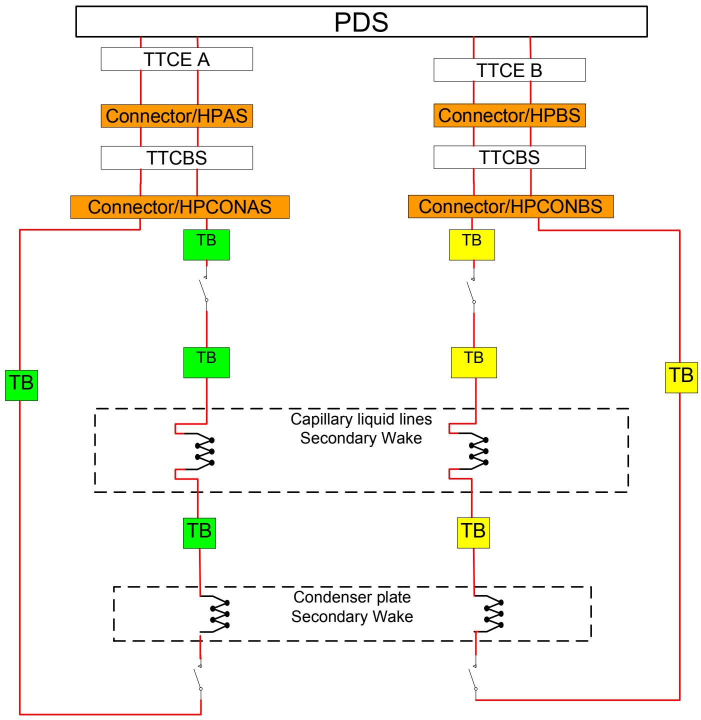


Figure 4-31: TTCS Wake Liquid line heaters schematic secondary condenser

The TTCS liquid line health heaters are labeled per heater section:

- HHLL1aP_RAM
- HHLL1aS_RAM
- HHLL1aP_WAK
- HHLL1aS_WAK

- HHLL1bP_RAM
- HHLL1bS_RAM
- HHLL1bP_WAK
- HHLL1bS_WAK

One section includes 1 wire heater with one foil heater in series as shown in Figure 4-31. The local connection of the wiring near the condenser manifolds is shown below.

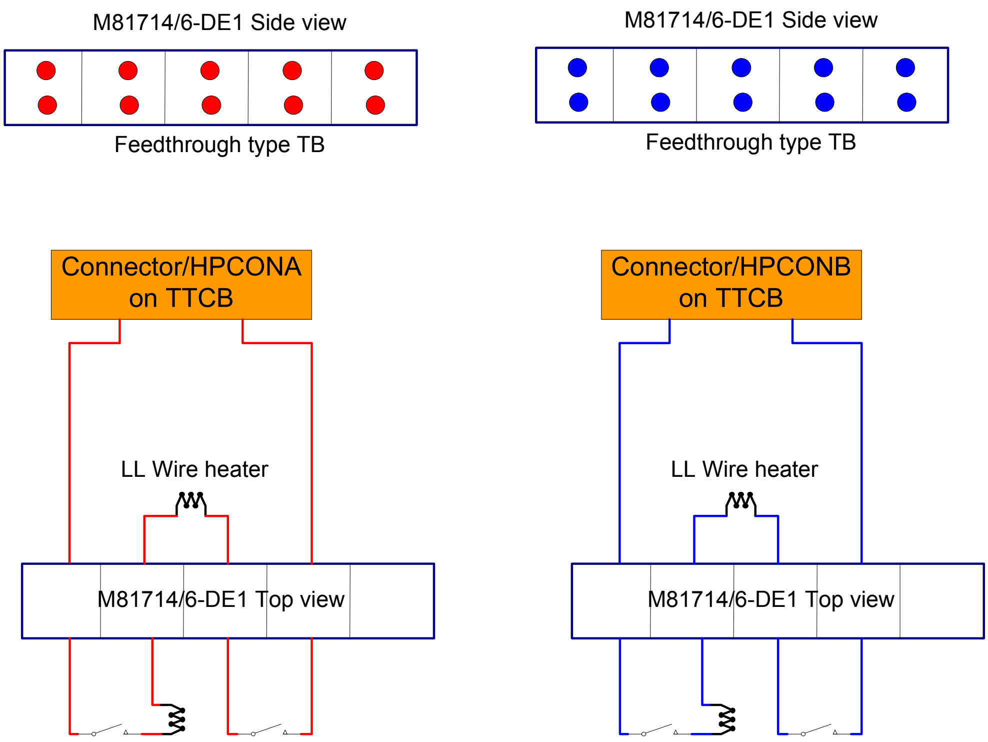


Figure 4-32: Terminal block cabling for foil and wire heater

A is connected to a single separate TB.

B is connected to a single separate TB.

The following terminal blocks are chosen for the liquid line heaters (Amphenolpcd):

- RAM primary condenser:
  1. TB1aP_RAM (Feed & Return, TTCE A, P, Foil heater) =====> M81714/6-DE1
  2. TB1bP_RAM (Feed & Return, TTCE A, P, Foil heater) =====> M81714/6-DE1
- RAM secondary condenser:
  1. TB1aS_RAM (Feed & Return, TTCE A, S, Foil heater) =====> M81714/6-DE1
  2. TB1bS_RAM (Feed & Return, TTCE A, S, Foil heater) =====> M81714/6-DE1
- WAKE primary condenser:
  1. TB1aP_WAKE (Feed & Return, TTCE A, P, Foil heater) ===> M81714/6-DE1
  2. TB1bP_WAKE (Feed & Return, TTCE A, P, Foil heater) ===> M81714/6-DE1
- WAKE secondary condenser:
  1. TB1aS_WAKE (Feed & Return, TTCE A, S, Foil heater) ===> M81714/6-DE1
  2. TB1bS_ WAKE (Feed & Return, TTCE A, S, Foil heater) ===> M81714/6-DE1

The terminal block T81714/6-DE1 locations on AMS are shown below.

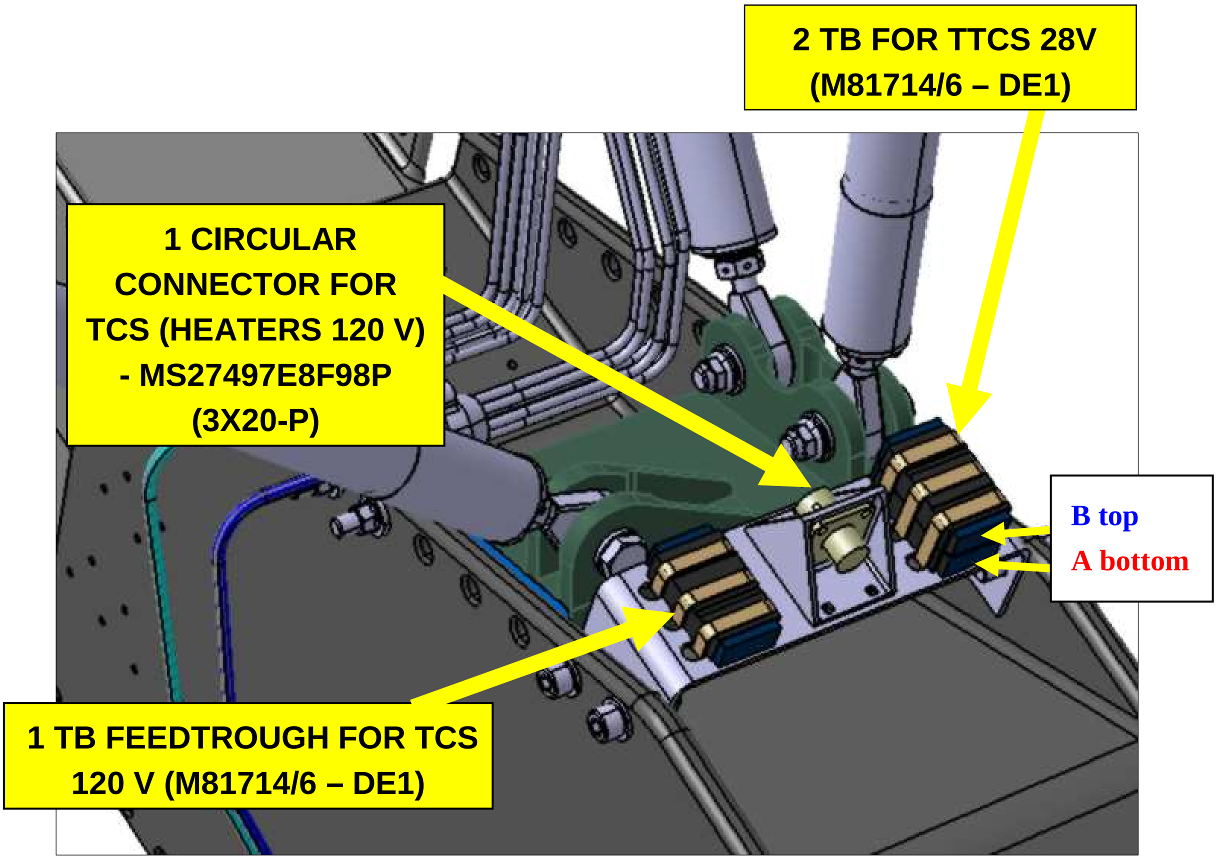


Figure 4-33: Terminal block locations liquid line heaters TB on the right

The mechanical TB location is shared with the terminal block and connector for the 120V heaters (see section 5). The TB specification is shown in below table in the last row.

Terminal Junction Modules
Series I - M81714/1, /6

MATERIALS

Module Body:
Polyetherimide per MIL-P-46184

Grommet:
Silicone blend elastomer

Contact Retainers:
Stainless Steel

Internal contact/bus system:
Copper alloy, gold finish per MIL-G-45204

OPERATING RANGE

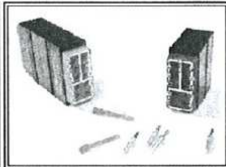
Temperature: -65¼ to 200¼C

Insulation Resistance:
5000 megohms @ 25¼

Dielectric Withstanding Voltage:
1500Vrms @ sea level
200Vrms @ 100,000 ft.

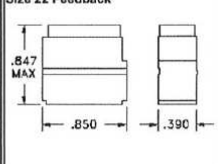
Current rating: 5 Amps

Vibration & Shock:
MIL-T-81714, para. 3.5.5 & 3.5.8

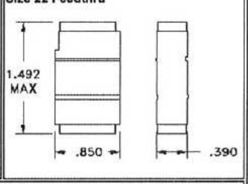


- High Reliability
- High temperature
- High fluid resistance
- Feedback and Feedthru
- Accepts 22, 24, 26 AWG

Size 22 Feedback



Size 22 Feedthru



Modules accommodate M39029/1-100, size 16/22*, pin contacts: Quantities: 10 Feedback, 20 Feedthru.

Feedback modules are shipped with one extra contact and two sealing plugs; feedthru modules are shipped with two extra contacts and four sealing plugs per MIL-T-81714.

Feedback modules readily install in both M81714/5 & /16 mounting tracks; feedthru modules readily install in M81714/10 mounting tracks.

* Mating pin / Wire barrel

BUSSING ARRANGEMENT	FEEDBACK		FEEDTHRU	
	MILITARY NO.	PCD NO.	MILITARY NO.	PCD NO.
	M81714/1-DA1	TJM122701	M81714/6-DA1	TJM222701
	M81714/1-DB1	TJM122702	M81714/6-DB1	TJM222702
	M81714/1-DB2	TJM122703	M81714/6-DB2	TJM222703
	M81714/1-DB3	TJM122704	M81714/6-DB3	TJM222704
	M81714/1-DC1	TJM122705	M81714/6-DC1	TJM222705
	M81714/1-DC2	TJM122706	M81714/6-DC2	TJM222706
	M81714/1-DC3	TJM122710		
	M81714/1-DC4	TJM122712		
	M81714/1-DD1	TJM122707	M81714/6-DD1	TJM222707
	M81714/1-DD2	TJM122711		
	M81714/1-DE1	TJM122708	M81714/6-DE1	TJM222708

Material and operational specifications Terminal blocks

Module Body: Polyetherimide per MIL-P-46184
Grommet: Silicone blend elastomer
Contact Retainers: Stainless Steel
Internal contact/bus system: Copper alloy, gold finish per MIL-G-45204

Temperature:	-65¼ to 200¼C
Insulation Resistance:	5000 megohms @ 25¼
Dielectric Withstanding Voltage:	1500Vrms @ sea level
	200Vrms @ 100,000 ft.
Current rating:	5 Amps
Vibration & Shock:	MIL-T-81714, para. 3.5.5 & 3.5.8

4.5.3 Thermostat specifications liquid line wire heaters

The thermostats used on the condenser brackets are the **700 series Thermal Switch** from **Honeywell** having the following characteristics**:**

- Ambient Temperature Range: -201 °C to +204 °C
- Specified Temp Set point Range: -17.2 °C to 121.1 °C
- Standard set-point Tolerance: ±2.8 °C
- The 700 series has supporting data at 1 amp 120VDC.

Specification of the dedicated thermostat:

- Honeywell TS701 Part no 701S090A130A
- Opening +54 °C/Closing +32 °C

The thermostats are glued onto the condenser brackets as shown in Figure 4-35 and Figure 4-36.

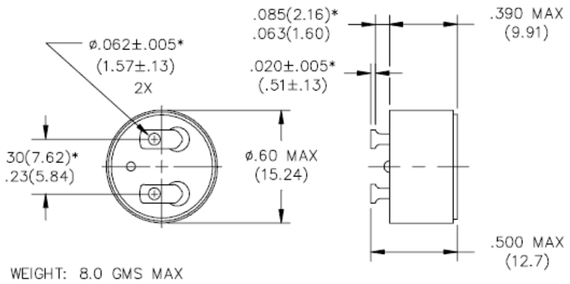
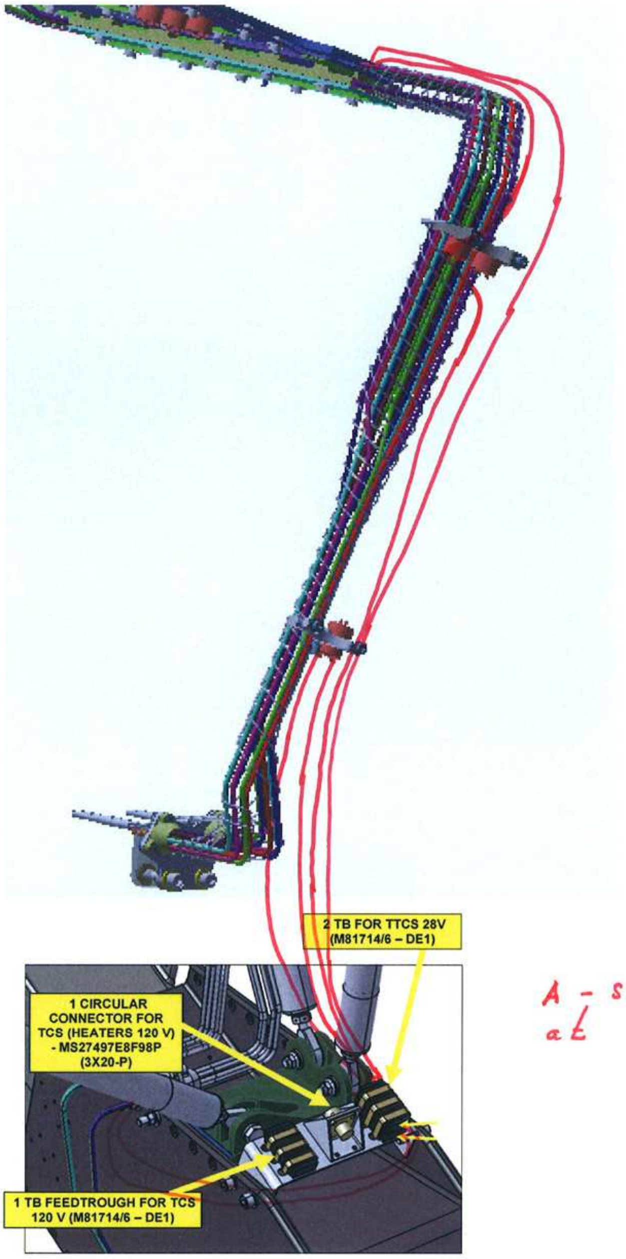


Figure 4-34: Honeywell 700 series layout (dimensions in inches)

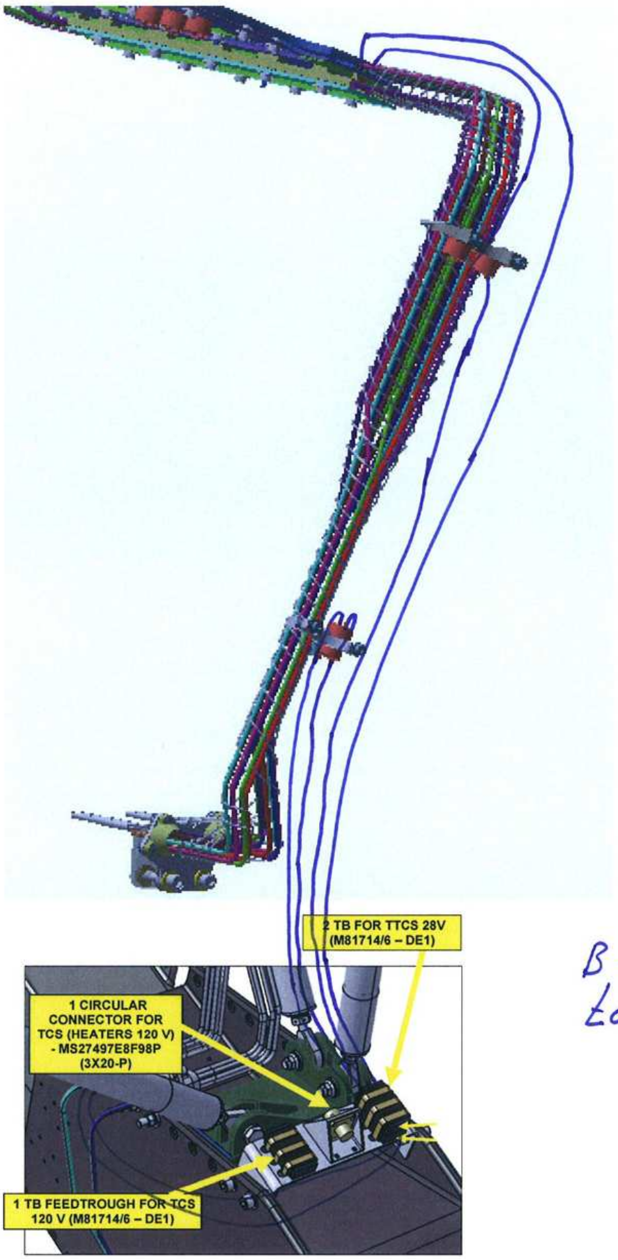
4.5.4 Electrical wiring mechanical sketch

In the below 2 pictures the wiring lay-out is shown in a mechanical sketch.



A - side connected at bottom. TB.

Figure 4-35: Wiring lay-out liquid line wire heaters A-side



B-side attached to top. TB

Figure 4-36: Wiring lay-out liquid line wire heaters B-side

This lay-out is similar for all four condensers.

4.5.5 TTCS liquid line health heater specifications

The liquid line heaters are placed around capillary liquid lines. Each condenser inlet/outlet will be equipped with two redundant wire heaters. The heaters will heat the volume wrapped by MLI and therefore also the condenser lines will be heated.

The wire heaters are chosen such that they deliver 1 Watt per condenser line. The foil heaters placed on the condenser plate is chosen such that it delivers app. 3 Watt to look after the heat leak to the condenser plate. The heaters chosen have the following specifications:

- R_{foil} = 7.3 Ohms
- R_{LL} = 41.7 Ohms
- R_{tot} = 49.0 Ohms

- I_{nom} = 28/49 = 0.57 Ampere (@ 28.0 Volts)
- $P_{con\_nom} = 0.57^2*7.3 = 2.38$ Watt
- $P_{LL\_nom} = 0.57^2 * 41.7 = 13.61$ Watt (13.61/14 = 0.97 Watt per liquid line)

- I_{max} = 29.5/49 = 0.60 Ampere (@ 29.5 Volts)
- $P_{con\_max} = 0.60^2*7.3 = 2.65$ Watt
- $P_{LL\_max} = 0.60^2 *41.7 = 15.11$ Watt (15.11/14 = 1.07 Watt per heater)

The selected elements for the liquid lines are the **ZUZ/15/4-336-4/HcAc** wire heaters of THERMOCOAX (www.thermocoax.com). This is a single core heater with cold ends. The wire chosen has a sheath metal of stainless steel. The ZUZ/HcAc wires have a line resistance per unit length of **12.4 ohms/m.**

These specifications are summarised in the following table:

	Liquid line heater (Wire)
Coating material	Stainless steel
Diameter	1.5 mm
Length cold/hot/cold	40 mm/3360mm/40mm
Resistance	41.7 Ohm
Power supply	28 Volt
Total Power nominal (approx)	13.61 Watt
Max Power density (@29.5V)	4.49 W/m
Connector type	CB05SPE/CEMENT8
Lead AWG	AWG 22

Table 4-2: Liquid line heater mechanical specifications

This wire heater is within the max power density requirement of 65.5 Watt/m.

The foil heater is chosen such that it has app. the dimensions: 1.5 cm width and 4.0 cm length. The foil heaters should deliver app. 3-4 Watt when placed in series with the parallel liquid line heaters as presented in the previous section. This resulted in the following Minco foil heater.

	Condenser plate heater
Heater Number	Minco Foil HK 5222
Length	58.4 * 10.7 mm
Resistance	7.3 Ohm
Nom Power supply	28 Volt
Nom Power (approx)	2.38 Watt
Max Power Density (@29.5V)	0.42 Watt/cm^2
Lead AWG	26
Connector type	I
Adhesive	Minco #15 Epoxy

Table 4-3: Condenser foil heater specifications

This foil heater is below the max power density requirement of 0.465 Watt/cm^2.

		Heater Location	Heater Type	Heater resistance Ω	Heater Power @ 28 Vdc	Number of wires	Wire: L [mm] Foil: LxH [mm]	Max power density @ 29,5V	Total Power W
A	RAM	Liquid Lines RAM Primary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Prim. Cond. Plate RAM	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	
		Liquid Lines RAM Secondary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Sec. Cond. Plate RAM	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	
	WAKe	Liquid Lines Wake Primary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Prim. Cond. Plate Wake	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	
		Liquid Lines Wake Secondary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Sec. Cond. Plate Wake	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	

		Heater Location	Heater Type	Heater resistance Ω	Heater Power @ 28 Vdc	Number of wires	Wire: L [mm] Foil: LxH [mm	Max power density @ 29,5V	Total Power W
B	RAM	Liquid Lines RAM Primary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Prim. Cond. Plate RAM	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	
		Liquid Lines RAM Secondary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Sec. Cond. Plate RAM	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	
	WAKe	Liquid Lines Wake Primary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Prim. Cond. Plate Wake	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	
		Liquid Lines Wake Secondary Loop	ZUZ/15/4-336-4/HcAc wire D = 1.5 mm 12.4 Ω/m	41.7	13.61	1	3360	4.49 [W/m]	16
		Sec. Cond. Plate Wake	Minco Foil HK 5222 58.4 * 10.7 mm	7.3	2.38	1	58.4 x 10.7	0.42 [W/cm^2]	

Figure 4-3: TTCS Liquid line heater specifications

4.5.6 TTCS liquid line health heaters design rationale

The sizing of wire liquid line heaters is based on the trade off between:

- Heating rate of the capillary liquid lines at cold conditions. The calculation is seen in appendix A
- Maximum temperature of the carbon fibre rods +100 ºC to which the condenser tubes are attached. Two thermostats per branch are present to avoid overheating of the rods.

The required branch heater power to heat up the condenser lines is estimated on 11 Watt.
The sizing of the Minco foil heaters attached on the condenser plate is based on the estimated heat leak from the liquid lines to the condenser plate; the calculation is seen in Appendix A.
The objective of the heater is to compensate the heat leak from the condenser lines to the condenser base plate. The required foil heater power is estimated on 3 Watt.

4.5.7 TTCS Liquid line heater safety and operational health measures

Non-operational and safety measures

In order to avoid overheating the carbon fibre rods (<+100 ºC) the liquid line health heaters are equipped with 2 TS per heater line (Opening +54 °C/Closing +32 °C). The thermostats are located on the condenser line brackets as shown in Figure 4-35 and Figure 4-36.
This safety measure keeps the Tracker rods below 100 C as is presented in the TTCS Safety approach RD-2 .

Operational health measures

In order to avoid the condenser inlet lines temperatures rise above set-point and critical temperatures the heaters are controlled by Pt1000's (Pt6aP, Pt7aP, Pt9aP, Pt10aP, Pt6aS, Pt7aS, Pt9aS, Pt10aS) during operation.
The TTCE switches off the heaters above -20 °C. This is shown in Figure 3-1.

5 TTCS 120 V heater design

5.1 Tracker radiator/condenser heaters (120 V)

The objective of the tracker radiator/condenser heaters is to defrost the Tracker radiator NH_3 HP's and CO_2 condensers.

5.1.1 Tracker radiator/condenser heaters location

The location of the Tracker radiators is shown in Figure 5-1.

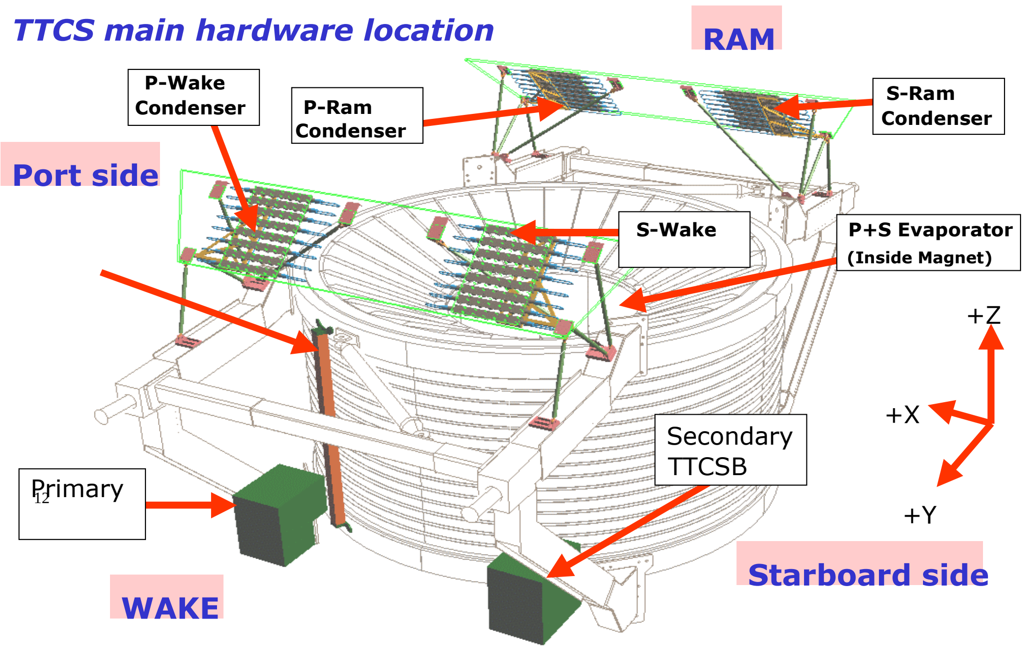


Figure 5-1: Location of Tracker radiators and condensers at RAM and Wake side

In more detail the radiator is shown in Figure 5-2.

Each Tracker radiator panel is equipped by 120Vdc Kapton foil heaters glued on the radiator backside face sheet. The layout of the heaters on the radiator is seen in Figure 5-2 and Figure 5-3. (With actual sizes of the foil heaters).The heaters are organised in 7 parallel branches. Five (5) are divided over the radiator and two (2) branches are divided over the condensers (one for each condenser). Condensers (mounted on the backside of the radiator panel) are equipped with 120Vdc Kapton foil heaters as well. Details of the heater locations on the condensers is found in Figure 5-4 to Figure 5-6.

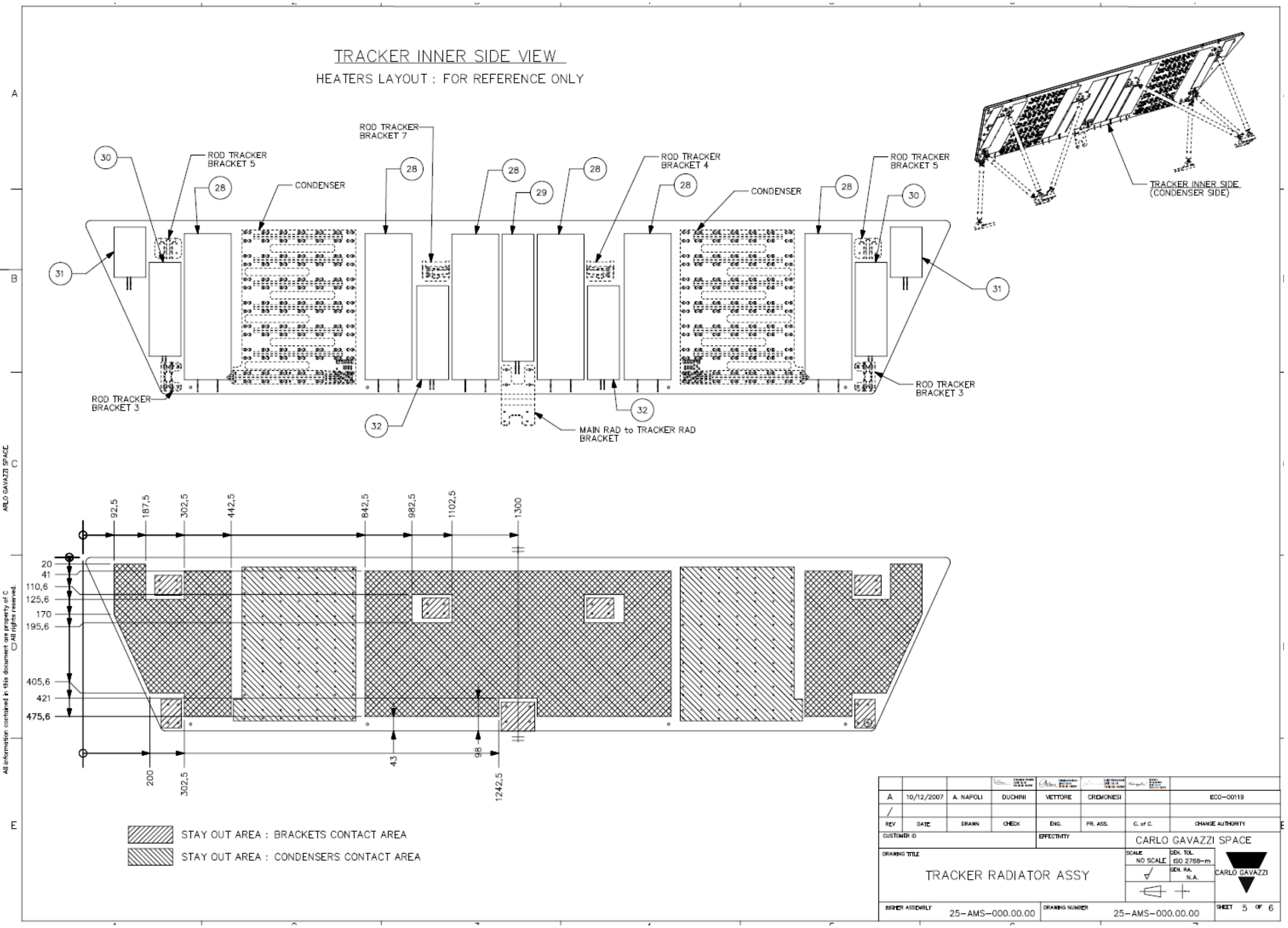


Figure 5-2: Tracker radiator and foil heaters layout with actual sizes

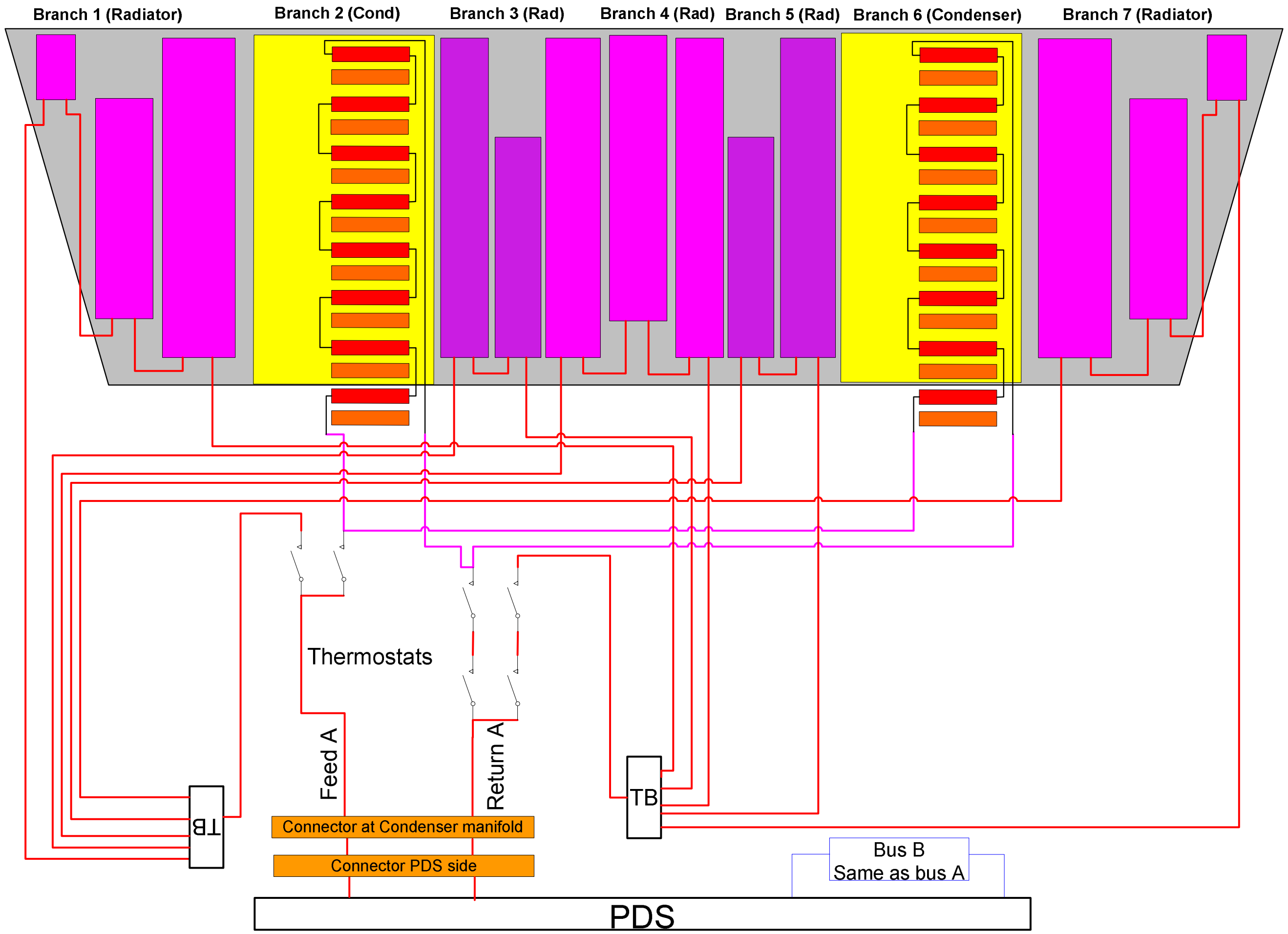
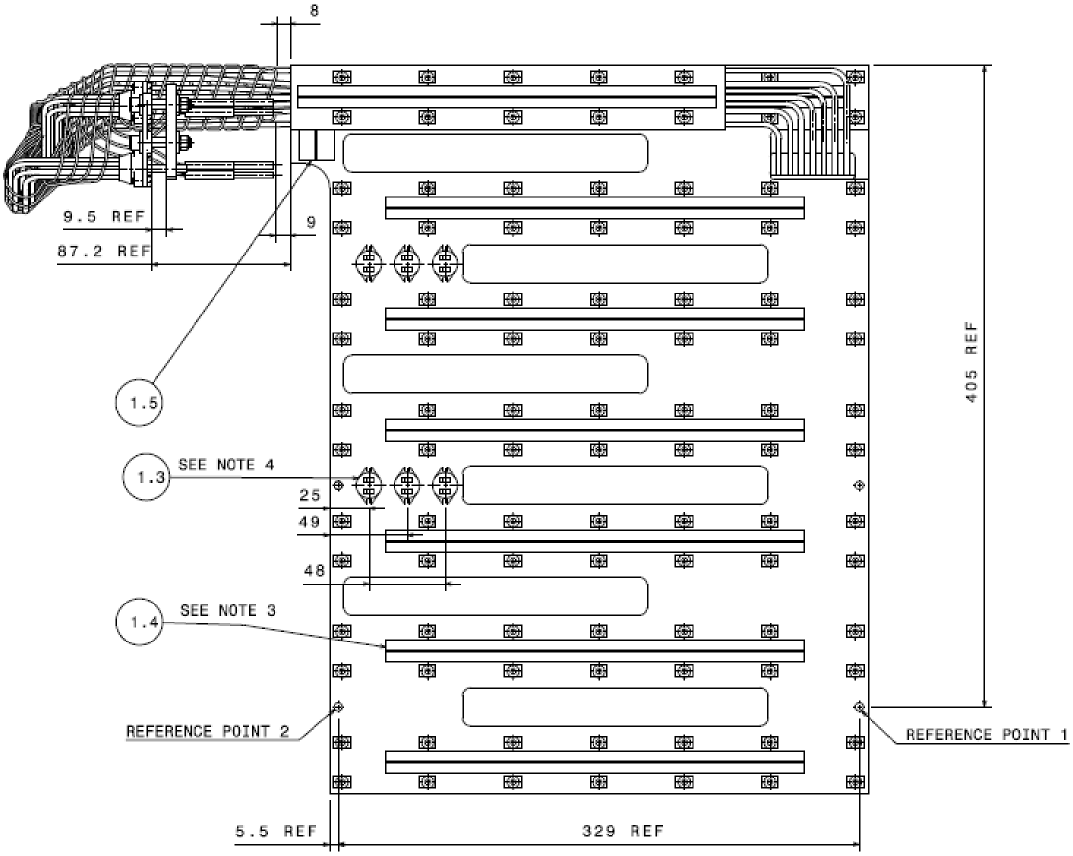


Figure 5-3: Tracker radiator lay-out with electronics wiring schematic (RAM is similar to WAKE)

The large foil heaters on the radiators are RICA double layer foil heaters, combining A and B heaters in one mechanical heater. The heaters on the condensers are single layer foil heaters. A and B heaters are located next to each other as shown in Figure 5-4 and .

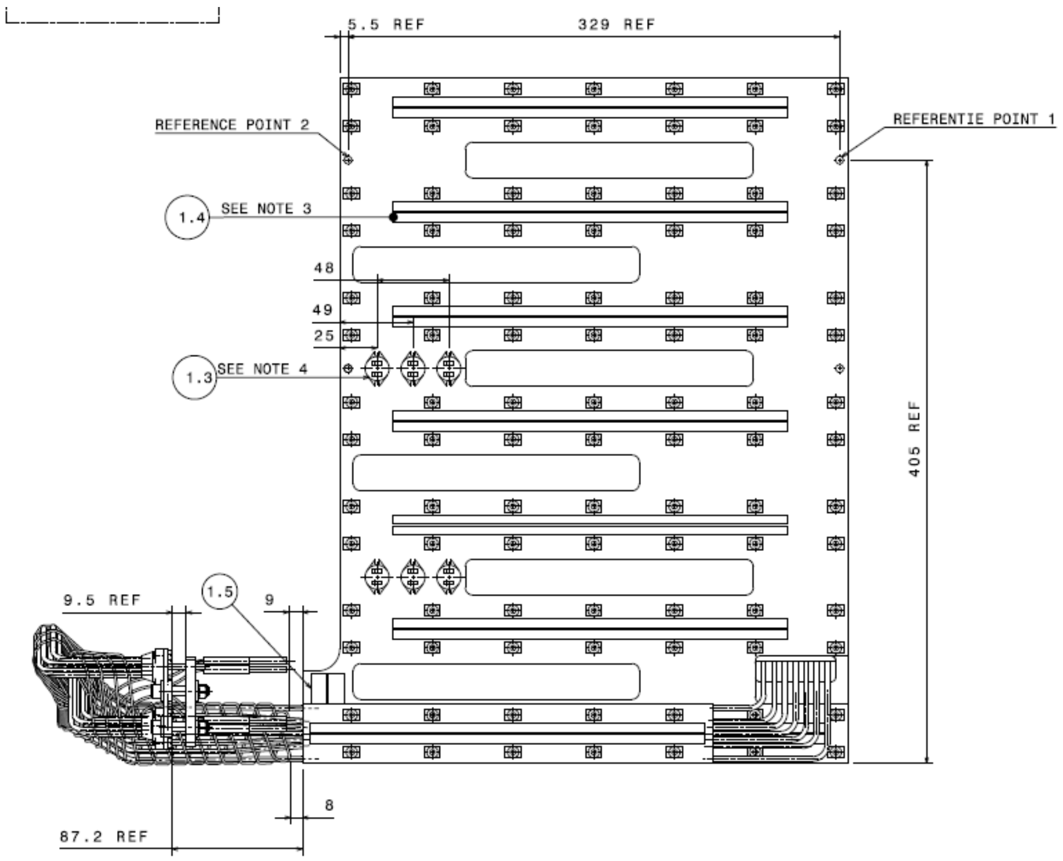
Figure 5-4: Mechanical location of the condenser heaters on the condenser back plates (only one condenser is shown)

Remark: The oval openings are open spaces in the condenser plates to reduce mass.



1.4	32	HEATER	Minco Foil HNK5203R48.4L12B, AWG 22, Type 9

Figure 5-5: Detailed heater design Primary Wake & Secondary RAM



1.4	32	HEATER	MINCO FOIL HNK5203R48.4L12B, AWG 22, TYPE 9

Figure 5-6: Detailed heater design Primary RAM & Secondary Wake

5.1.2 Tracker radiator/condenser heater electronic lay-out

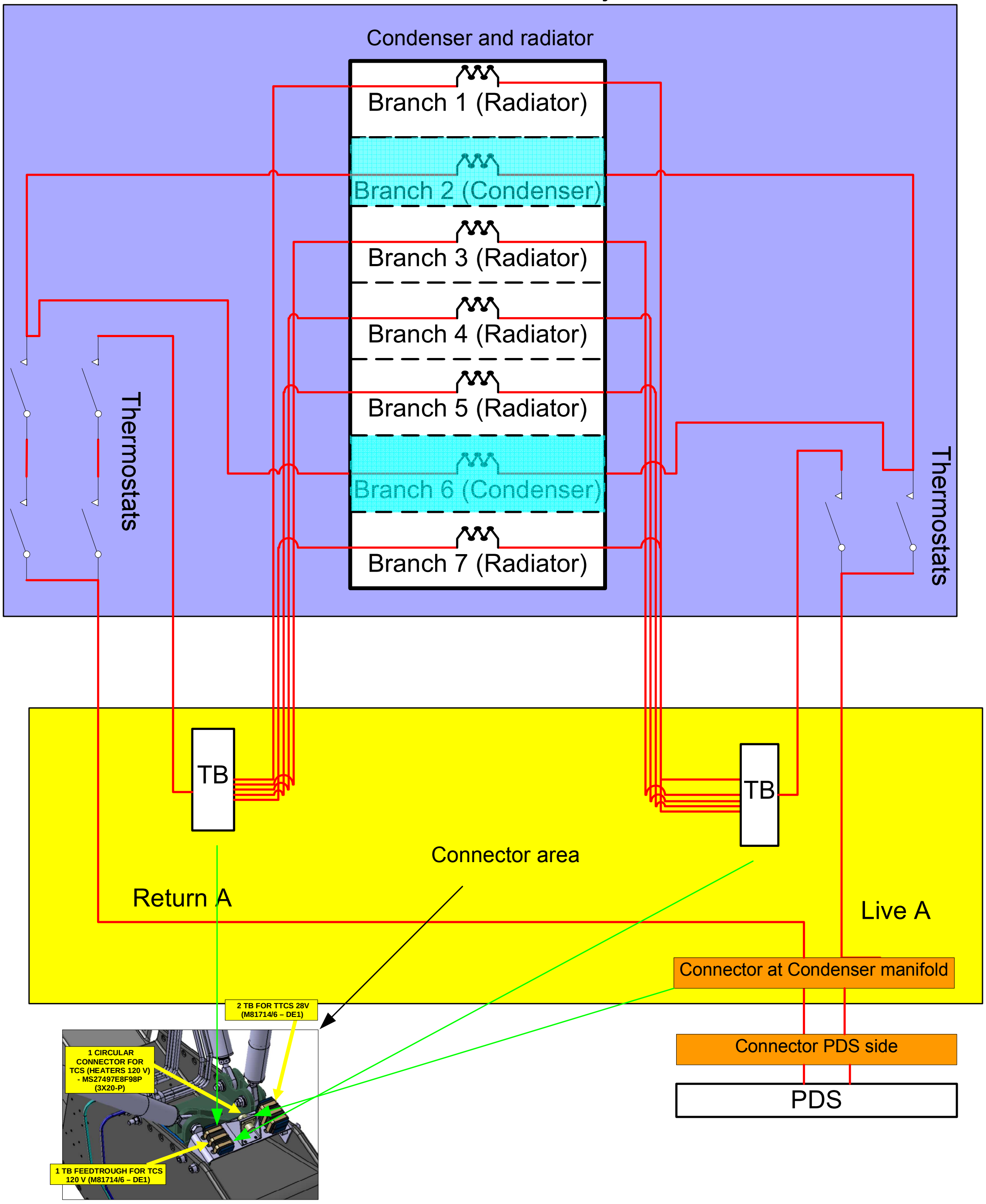


Figure 5-7: Tracker radiator/condenser heater electronic lay-out RAM (The B-side schematics is similar but not shown)

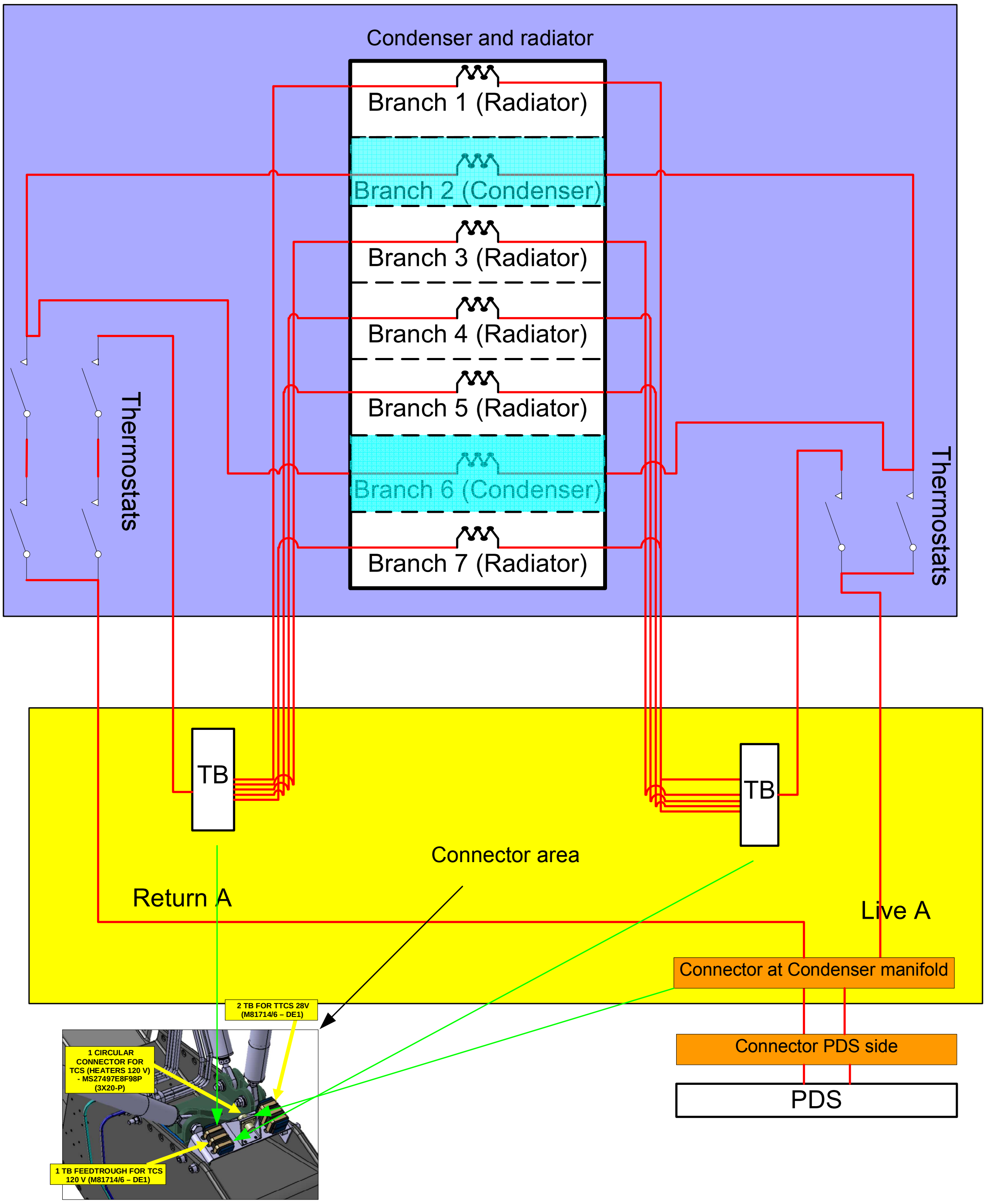


Figure 5-8: Tracker radiator/condenser heater electronic lay-out Wake (The B-side schematics is similar but not shown)

The schematics of the RAM and Wake radiator/condenser heaters are shown in Figure 5-7 and Figure 5-8. The heaters are powered by bus A and B of the PDS.

The heater schematic shows 7 parallel branches connected to one PDS line. The PDS line is first divided in 2 sub-branches of respectively 5 radiator branches and 2 condenser branches. Reason for this is two-fold:

- For integration purposes the condenser branches need to be mechanically as independent possible from the radiator branches.
  N.B. The radiator will be integrated later in the AMS integration sequence
- The thermostats located on the radiator have a current limit of 1 A. Therefore the power lines need to be split to reduce the current below 1 A through one thermostat.

All heaters on one Tracker radiator including condensers heaters are switched by thermostats at the same temperature on the same location. For integration reasons the thermostats will be located on the condenser construction.
The thermostat rationale is as follows:

- For the safety critical condenser heater branches located on the CO_2 condensers one (1) thermostat is located in the feed line and two (2) in the return line.
- The Same is done for the radiator heaters

Thermostat set-point for all thermostats in the tracker radiator/condenser heater schematic:

- Nominal operation (No heat)
- Threshold temperature for closing -35°C
- Threshold temperature for opening -25°C

The heaters should bring the radiator to a temperature of -40 °C.

Due to heater design with thermostats the design is two-fault tolerant for the condenser heaters and the design is inherent safe. The condenser heaters can not raise the temperature of the condenser to the Maximum Design Temperature of -5 °C during melting (see also NLR-Memorandum AMSTR-NLR-TN-039-Issue03 “TTCS Condenser Freezing Test Report”). The same thermostat configuration is applicable for the radiator branches.

5.1.3 Tracker radiator/condenser heater specifications

The following heaters are chosen for the tracker radiator (numbers per Radiator):

Model Number	Size [mm] X	Size [mm] Y	Type	Resistance [ohms]	Lead wire AWG	Effective area [cm^2]	Number (total number)
1EFISG287001	140	430	Dual layer	300+300	24	602	6 (12)
1EFISG288001	95	280	Dual layer	200+200	24	266	2 (4)
1EFISG289001	95	150	Dual layer	229+229	24	142.5	2 (4)
1EFISG290001	95	280	Dual layer	400+400	24	266	2 (4)
1EFISG291001	95	380	Dual layer	100+100	24	361	1 (2)

Table 5-1: Radiator RICA heater specifications

The radiator heaters are double layer Rica foil heaters combining the A & B side heaters in one foil. The

The condenser heater specifications are summarised in Table 5-2. These heaters are single layer Minco kapton foil heaters 5203 (alias HK27565) type 05 heaters with PSA #10 backing. Redundant heaters are glued next to each other.

Model Number	Size [mm] X	Size [mm] Y	Type	Resistance [ohms]	Lead wire AWG	Effective area [cm^2]	Number
5203	6.4	264.2	Type 05	48.4	22	16.90	16 (per cond) 32 (per rad) 64 (total)

Table 5-2: Condenser Minco foil heater specifications

The power distribution per branch on the radiator (@113 V) is summarized in the next table:

	Branch number	Branch Resistance [Ω]	Current [A] @113 V	TS Current [A] @ 113 V	Power [W] @ 113 V
Rad	1	729	0.155	**0.794**	17.5
	3	700	0.161		18.2
	4	700	0.161		18.2
	5	700	0.161		18.2
	7	729	0.155		17.5
Cond	2	387.2	0.292	**0.584**	33.0
	6	387.2	0.292		33.0
	Total	**82.0**	**1.378**		**155.7**

Table 5-3: Power current distribution @ 113Vdc over the branches, (TS: thermostats)

The power distribution per branch on the radiator (@126.5) is summarized in the next table:

	Branch number	Branch Resistance [Ω]	Current [A] @126.5 V	TS Current [A] @ 126.5 V	Power [W] @ 126.5 V
Rad	1	729	0.174	**0.889**	21.95
	3	700	0.181		22.86
	4	700	0.181		22.86
	5	700	0.181		22.86
	7	729	0.174		21.95
Cond	2	387.2	0.327	**0.654**	41.33
	6	387.2	0.327		41.33
	Total	**82.0**	**1.543**		**195.1**

Table 5-4: Power current distribution @ 126.5 Vdc over the branches, (TS: thermostats)

More details on the number of heaters, heat fluxes and resistances can be found in Table 5-3.

The thermostats used on the radiator are the **700 series Thermal Switch** from **Honeywell** having the following characteristics**:**

- Ambient Temperature Range: -201 °C to +204 °C
- Specified Temp Set point Range: -49 °C to -17.8 °C
- Standard set-point Tolerance: ±3.3 °C
- The 700 series has supporting data at 1 amp 120VDC.

Specification of the dedicated thermostat:

- Honeywell TS705 Part no G311P641/03705S-13A005
- Opening -15 °C/Closing -25 °C

The thermostats are glued onto the condenser and the radiator structure.

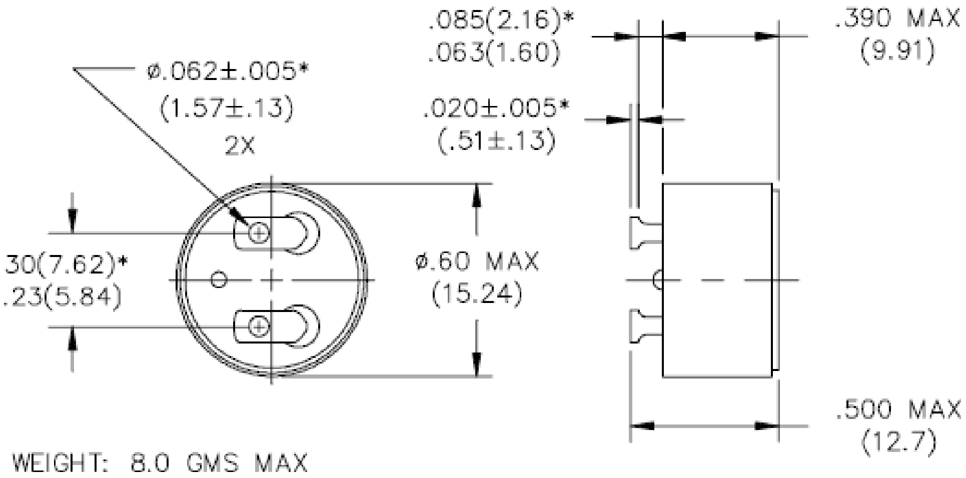
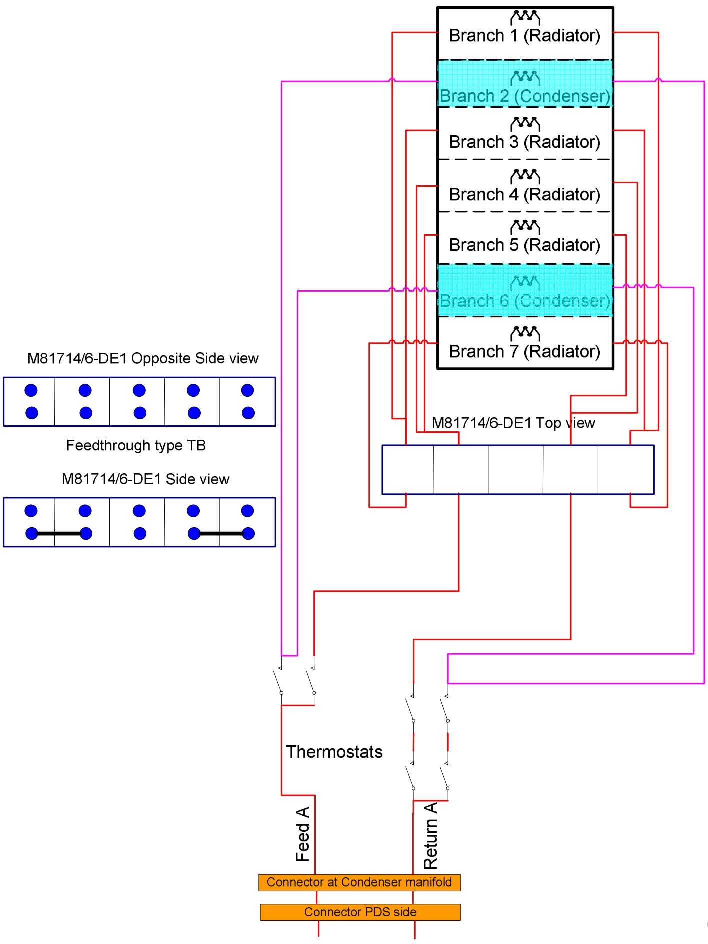


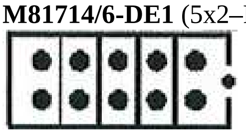
Figure 5-1: Honeywell 700 series layout (dimensions in inches)

5.1.4 Radiator terminal blocks/junctions

First the



The terminal block (TB) used to connect the radiator wires are aphenol terminal junctions (www.aphenolpcd.com). The **M81714/6-DE1** (5x2–Feed through type) .



And for the second split 2 terminal blocks (A,B with +/- on the same block) type (2x6, 2x4 – double ended type).

Total 4 terminal blocks are needed for the line#4 (Wake Tracker radiator). The same for the other radiator. Total 8 are needed : 2 terminal blocks type *(A,B)*(Ram,Wake) ; +/- on the same block.

PDS bus	PDS Line	Location on radiator	# of patches Type RICA (unless incicated)	Total Heaters resistance	Total Heaters Area, [cm^2]	Total power consumption @ 113 Vdc [W]		Power Density @ 113 Vdc [Watt/cm^2]	Total power consumption @ 126.5 Vdc [W]		Power Density @ 126.5 Vdc [Watt/cm^2]
A	Line10 Ram	Branch 1 Side radiator	1EFISG289001	729	1010	17.5	155.7	0.04	21.95	195.14	0.05
			1EFISG288001					0.02			0.02
			1EFISG287001					0.01			0.02
		Branch 2 Condenser	Minco 8 * 5203	387.2	135.27	33.0		0.24	41.33		0.31
		Branch 3 Mid radiator	1EFISG287001	700	868	18.2		0.01	22.86		0.02
			1EFISG290001					0.04			0.05
		Branch 4 Mid radiator	2x 1EFISG287001	700	1565	18.2		0.01	22.86		0.02
								0.01			0.01
			1EFISG291001					0.01			0.02
		Branch 5 Mid radiator	1EFISG287001	700	868	18.2		0.01	22.86		0.02
			1EFISG290001					0.04			0.05
		Branch 6 Condenser	Minco 8 * 5203	387.2	135.27	33.0		0.24	41.33		0.31
		Branch 7 Side radiator	1EFISG289001	729	1010	17.5		0.04	21.95		0.05
			1EFISG288001					0.02			0.02
			1EFISG287001					0.01			0.02

PDS bus	PDS Line	Location on radiator	# of patches Type RICA (unless incicated)	Total Heaters resistance	Total Heaters Area, [cm^2]	Total power consumption @ 113 Vdc [W]		Power Density @ 113 Vdc [$Watt/cm^2$]	Total power consumption @ 126.5 Vdc [W]		Power Density @ 126.5 Vdc [$Watt/cm^2$]
A	Line10 Wake	Branch 1 Side radiator	1EFISG289001	729	1010	17.5	155.7	0.04	21.95	195.14	0.05
			1EFISG288001					0.02			0.02
			1EFISG287001					0.01			0.02
		Branch 2 Condenser	Minco 8 * 5203	387.2	135.27	33.0		0.24	41.33		0.31
		Branch 3 Mid radiator	1EFISG287001	700	868	18.2		0.01	22.86		0.02
			1EFISG290001					0.04			0.05
		Branch 4 Mid radiator	2x 1EFISG287001	700	1565	18.2		0.01	22.86		0.02
								0.01			0.01
			1EFISG291001					0.01			0.02
		Branch 5 Mid radiator	1EFISG287001	700	868	18.2		0.01	22.86		0.02
			1EFISG290001					0.04			0.05
		Branch 6 Condenser	Minco 8 * 5203	387.2	135.27	33.0		0.24	41.33		0.31
		Branch 7 Side radiator	1EFISG289001	729	1010	17.5		0.04	21.95		0.05
			1EFISG288001					0.02			0.02
			1EFISG287001					0.01			0.02

PDS bus	PDS Line	Location on radiator	# of patches Type RICA (unless incicated)	Total Heaters resistance	Total Heaters Area, [cm^2]	Total power consumption @ 113 Vdc [W]		Power Density @ 113 Vdc [Watt/cm^2]	Total power consumption @ 126.5 Vdc [W]		Power Density @ 126.5 Vdc [Watt/cm^2]
B	Line10 Ram	Branch 1 Side radiator	1EFISG289001	729	1010	17.5	155.7	0.04	21.95	195.14	0.05
			1EFISG288001					0.02			0.02
			1EFISG287001					0.01			0.02
		Branch 2 Condenser	Minco 8 * 5203	387.2	135.27	33.0		0.24	41.33		0.31
		Branch 3 Mid radiator	1EFISG287001	700	868	18.2		0.01	22.86		0.02
			1EFISG290001					0.04			0.05
		Branch 4 Mid radiator	2x 1EFISG287001	700	1565	18.2		0.01	22.86		0.02
								0.01			0.01
			1EFISG291001					0.01			0.02
		Branch 5 Mid radiator	1EFISG287001	700	868	18.2		0.01	22.86		0.02
			1EFISG290001					0.04			0.05
		Branch 6 Condenser	Minco 8 * 5203	387.2	135.27	33.0		0.24	41.33		0.31
		Branch 7 Side radiator	1EFISG289001	729	1010	17.5		0.04	21.95		0.05
			1EFISG288001					0.02			0.02
			1EFISG287001					0.01			0.02

PDS bus	PDS Line	Location on radiator	# of patches Type RICA (unless incicated)	Total Heaters resistance	Total Heaters Area, [cm^2]	Total power consumption @ 113 Vdc [W]		Power Density @ 113 Vdc [Watt/cm^2]	Total power consumption @ 126.5 Vdc [W]		Power Density @ 126.5 Vdc [Watt/cm^2]
B	Line10 Wake	Branch 1 Side radiator	1EFISG289001	729	1010	**17.5**	**155.7**	**0.04**	**21.95**	**195.14**	**0.05**
			1EFISG288001					**0.02**			**0.02**
			1EFISG287001					**0.01**			**0.02**
		Branch 2 Condenser	Minco 8 * 5203	387.2	135.27	**33.0**		**0.24**	**41.33**		**0.31**
		Branch 3 Mid radiator	1EFISG287001	700	868	**18.2**		**0.01**	**22.86**		**0.02**
			1EFISG290001					**0.04**			**0.05**
		Branch 4 Mid radiator	2x 1EFISG287001	700	1565	**18.2**		**0.01**	**22.86**		**0.02**
								0.01			**0.01**
			1EFISG291001					**0.01**			**0.02**
		Branch 5 Mid radiator	1EFISG287001	700	868	**18.2**		**0.01**	**22.86**		**0.02**
			1EFISG290001					**0.04**			**0.05**
		Branch 6 Condenser	Minco 8 * 5203	387.2	135.27	**33.0**		**0.24**	**41.33**		**0.31**
		Branch 7 Side radiator	1EFISG289001	729	1010	**17.5**		**0.04**	**21.95**		**0.05**
			1EFISG288001					**0.02**			**0.02**
			1EFISG287001					**0.01**			**0.02**

Table 5-5: Tracker radiator/condenser heater details

Appendix 1: Heater sizing liquid line heaters

TTCS Liquid Line Heaters Sizing

Maximum temperature at hot condition:

$D_{oMLI} := 15 \cdot mm$ $\quad L_1 := 3.0 \cdot m$ $\quad \sigma := 5.6 \times 10^{-8} \cdot \frac{W}{m^2 \cdot K^4}$ $\quad \varepsilon_{IR} := 0.05$

$A1 := 2 \cdot \pi \cdot D_{oMLI} \cdot L_1$ $\quad A1 = 2.827 \times 10^5\, mm^2$

$Tenv := 303 \cdot K$ $\quad P_{LLheaters} := 10.5 \cdot W$

$$T_b := \left(Tenv^4 + \frac{P_{LLheaters}}{\sigma \cdot A1 \cdot \varepsilon_{IR}} \right)^{0.25}$$

$T_b = 383.773\, K$ $\quad T_{b\,Celscius} := T_b - 273 \cdot K$ $\quad T_{b\,Celscius} = 110.773\, K$

Liquid lines heating rate at cold conditions:

$n := 6$ $\quad Cp_{co2} := 2510 \cdot \frac{J}{kg \cdot K}$ $\quad Cp_{inconel} := 435 \cdot \frac{J}{kg \cdot K}$ $\quad \rho_{inconel} := 8190 \cdot \frac{kg}{m^3}$

$\rho_{co2} := 929 \cdot \frac{kg}{m^3}$ $\quad D_{in} := 1 \cdot mm$ $\quad D_{out} := 3 \cdot mm$

$$M_{co2} := \frac{\pi}{4} \cdot D_{in}^2 \cdot L_1 \cdot \rho_{co2}$$

$$M_{inconel} := \frac{\pi}{4} \cdot \left(D_{out}^2 - D_{in}^2 \right) \cdot L_1 \cdot \rho_{inconel} \qquad Dtdt := \frac{P_{LLheaters}}{n \cdot \left(Cp_{co2} \cdot M_{co2} + Cp_{inconel} \cdot M_{inconel} \right)}$$

$Dtdt = 1.445\, K\,min^{-1}$

Estimation capillary liquid lines heat leak rate (at condenser side):

$d_o := 3\cdot mm$ $\quad d_{in} := 1\cdot mm$ $\quad L_2 := 0.05\cdot m$

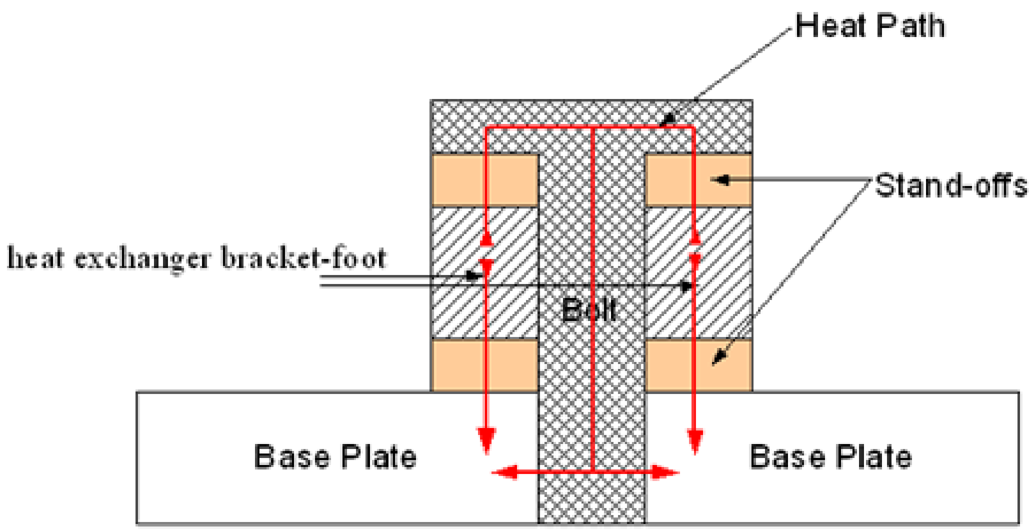
$A_2 := \frac{n\pi}{4}\cdot\left(d_o^{\,2} - d_{in}^{\,2}\right)$ $\quad A_2 = 3.77\times 10^{-5}\,m^2$

$k_{ss} := 15\cdot\frac{W}{K\cdot m}$ $\quad G_{loss} := k_{ss}\cdot\frac{A_2}{L_2}$ $\quad DT := 100\cdot K$

$P_{loss} := G_{loss}\cdot DT$

$P_{loss} = 1.131\,W$

Appendix 2: Conductance of bolt connection between the heat exchanger and base plate



Material Properties:

Inconel	SS
$k_{inc} := 15.5 \frac{W}{m \cdot K}$	$k_{SS} := 15.3 \frac{W}{m \cdot K}$
$C_{p\_inc} := 480 \frac{J}{kg \cdot K}$	$C_{p\_SS} := 480 \frac{J}{kg \cdot K}$
$\rho_{inc} := 8440 \cdot \frac{kg}{m^3}$	$\rho_{SS} := 7800 \cdot \frac{kg}{m^3}$

Contact Conductance:

$$C_{cont} := 500 \cdot \frac{W}{m^2 \cdot K}$$

Dimensions

$H_{StO} := 1.0mm$

$H_{BP} := 10mm$

$H_{HX} := 10mm$

$H_{BoltCyl} := 22mm$

$H_{BoltHead} := 5mm$

$D_{in} := 5mm$

$D_{out} := 10mm$

$A_{HX} := \left(D_{out}^2 - D_{in}^2\right)\cdot\frac{\pi}{4}$ $\quad A_{HX} = 58.905mm^2$

$A_{Blts} := \left(D_{in}^2\right)\cdot\frac{\pi}{4}$ $\quad A_{Blts} = 19.635mm^2$

$A_{Blts\_BP} := \pi \cdot D_{out} \cdot H_{BP}$ $\quad A_{Blts\_BP} = 314.159mm^2$

$R_{HX} := \frac{H_{HX}}{k_{inc} \cdot A_{HX}}$ $\quad R_{HX} = 10.953\frac{K}{W}$

$R_{cont} := \left(c_{cont} \cdot A_{HX}\right)^{-1}$ $\quad R_{cont} = 33.953\frac{K}{W}$

$R_{StO} := \frac{H_{StO}}{k_{SS} \cdot A_{HX}}$ $\quad R_{StO} = 1.11\frac{K}{W}$

$R_{blts} := \frac{H_{BoltCyl}}{k_{SS} \cdot A_{Blts}}$ $\quad R_{blts} = 73.232\frac{K}{W}$

$R_{Blts\_BP} := \left(c_{cont} \cdot A_{Blts\_BP}\right)^{-1}$ $\quad R_{Blts\_BP} = 6.366\frac{K}{W}$

$R1 := \frac{R_{HX}}{2} + R_{cont} + R_{StO} + R_{con}$ $\quad R1 = 74.492\frac{K}{W}$

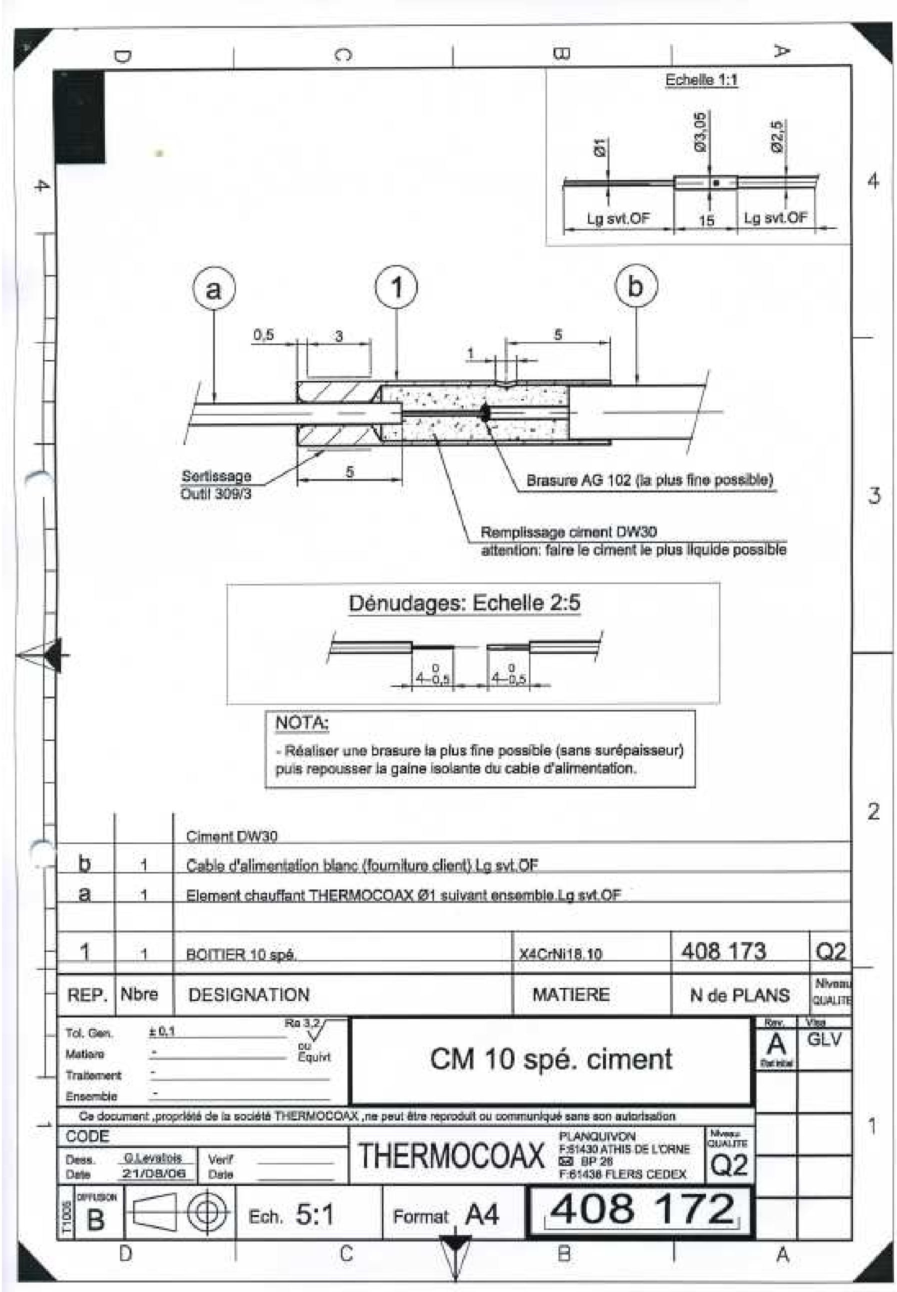
$R2 := \frac{R_{HX}}{2} + R_{cont} + R_{StO} + R_{cont} + R_{blts} + R_{Blts\_Bl}$ $\quad R2 = 154.09\frac{K}{W}$

$G1 := \frac{1}{R1}$ $\quad G1 = 0.013\frac{W}{K}$

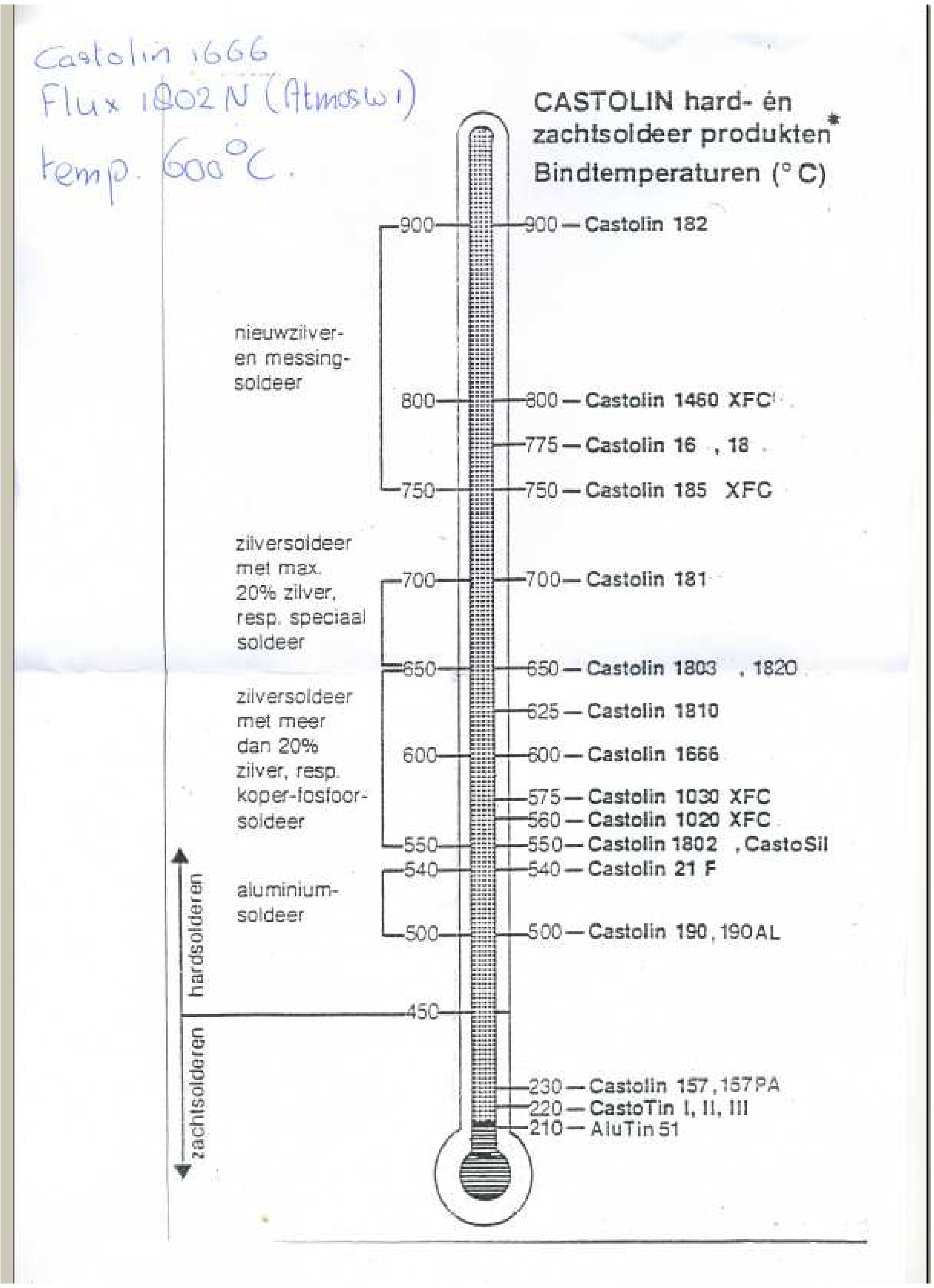
$G2 := \frac{1}{R2}$ $\quad G2 = 6.49\times 10^{-3}\frac{W}{K}$

$G_{tot\_Bolt} := G1 + G2$ $\quad G_{tot\_Bolt} = 0.02\frac{W}{K}$

Appendix 03: Properties Thermocoax CB and CM special connectors with Cement8



Appendix 04: Recommended Soldering by Thermocoax



Appendix 05: Technical Properties Cement8 (Page01)

SAUEREISEN

ELECTROTEMP CEMENT NO. 8

Superior electrical insulation for:

Appliances
Furnaces
Heating elements
Lamp assemblies
Resistors

Sauereisen Electrotemp Cement No. 8 is primarily used where high electrical insulation and thermal conductivity are desired. No. 8 cures by a chemical-set and is ideal for potting applications subject to high temperature and/or thermal shock. Formulated with a zircon base, the cement is non-corrosive and compatible for applications with ceramics, glass and most metals. The material is supplied in Powder form and need only be mixed with water to apply.

CHARACTERISTICS

- ☐ Provides maximum electrical resistance.
- ☐ Heat conductive and thermal shock resistant.
- ☐ Withstands temperatures to 2,600°F (1,426°C).
- ☐ Easy to mix and apply.
- ☐ Ideal for potting applications.
- ☐ Chemical set.
- ☐ Odorless.

APPLICATION

Sauereisen Electrotemp Cement No. 8 Powder should be thoroughly remixed before using. Weigh approximately 100 parts Powder and 13 parts water. Place Powder in a clean mixing container. Add water to the Powder at one time while mixing - do not add water gradually. Continue mixing until a smooth, uniform consistency is obtained. Mixing may be done with a slow-speed mixer or by hand with a spatula.

PHYSICAL PROPERTIES

Coefficient of thermal expansion	2.6 x 10^{-6}/F° (4.68 x 10^{-6}/C°)
Color	Off white
Compressive strength	3,000 psi (210 kg/cm^2)
Density	160 pcf (2.56 gm/cm^3)
Dielectric constant	3.0 - 4.0
Dielectric strength	
@ 70°F (21°C)	76.0 to 101.5 Volts/mil (2,900 to 3,900 Volts/mm)
@ 750°F (398°C)	25.0 to 38.0 Volts/mil (980 to 1,490 Volts/mm)
@ 1,475°F (801°C)	12.5 to 25.0 Volts/mil (490 to 980 Volts/mm)
Maximum service temperature	2,600°F (1,426°C)
Mix ratio (Powder:water, by weight)	100:13
Modulus of rupture	900 psi (63 kg/cm^2)
Tensile strength	400 psi (28 kg/cm^2)
Thermal conductivity	8 - 11 Btu·in/ft^2·hr·°F (2.7 - 3.8 x 10^{-3} Cal·cm/cm^2·sec·°C)
Volume resistivity	
@ 70°F (21°C)	10^{10} - 10^{11} ohm-cm
@ 750°F (398°C)	10^{8} - 10^{10} ohm-cm
@ 1,475°F (801°C)	10^{8} - 10^{9} ohm-cm

Physical properties were determined on specimens prepared under laboratory conditions using applicable ASTM procedures. Actual field conditions may vary and yield different results; therefore, data are subject to reasonable deviation.

Minimum amount of water should be used as excess water reduces mechanical strength, increases shrinkage and delays set time. Failure of cement to adhere indicates setting has begun - discard cement. Do not attempt to retemper by adding more water. Porous substrates may require dampening with Sauereisen Thinning Liquid No. 14 prior to cement application.

SETTING/CURING

Electrotemp Cement No. 8 hardens with an internal chemical-setting action after 18-24 hours at ambient temperature. Working time of No. 8 when Powder is mixed with water is approximately 30 minutes at 70°F. If it is desired to accelerate the cure, low temperature oven drying at 180°F can be used. Avoid steaming while drying. Proper curing of No. 8 is critical to developing maximum strengths. If the cement will be exposed to elevated temperatures, constant water immersion or steam environments, consult Sauereisen for an appropriate drying schedule recommendation.

For higher humidity resistance where it is impractical to fire cement, a moisture-resistant lacquer or silicone coating should be applied to the exposed surfaces.

PACKAGING

Standard packaging for Electrotemp Cement No. 8 is 50 lb. bags. Small packaging in quarts and gallons is available, too. Consult Sauereisen for pricing of special packaging in pails.

Appendix 05: Technical Properties Cement8 (Page02)

SHELF LIFE

Sauereisen No. 8 Powder has a shelf life of one year when stored in unopened, tightly sealed containers in a dry location at 70ºF. If there is a doubt as to the quality of the material, consult Sauereisen.

CAUTION

Consult Material Safety Data Sheets and container label Caution Statements for any hazards in handling this material.

CLEAN-UP

All equipment should be cleaned with soap and water before No. 8 cures. If removal is required after cure, consult Sauereisen for recommendations.

WARRANTY

We warrant that our goods will conform to the description contained in the order, and that we have good title to all goods sold. WE GIVE NO WARRANTY, WHETHER OF MERCHANTABILITY, FITNESS FOR PURPOSE OR OTHERWISE, EXPRESS OR IMPLIED, OTHER THAN AS EXPRESSLY SET FORTH HEREIN. We are glad to offer suggestions or to refer you to customers using Sauereisen cements and compounds for a similar application. Users shall determine the suitability of the product for intended application before using, and users assume all risk and liability whatsoever in connection therewith regardless of any suggestions as to application or construction. In no event shall we be liable hereunder or otherwise for incidental or consequential damages. Our liability and your exclusive remedy hereunder or otherwise, in law or in equity, shall be expressly limited to our replacement of nonconforming goods at our factory or, at our sole option, to repayment of the purchase price of nonconforming goods.

- ☐ **Information concerning government safety regulations available upon request.**
- ☐ **Sauereisen also produces compounds for corrosion resistance, electrostatic discharge and grouting.**

SAUEREISEN ...since 1899
160 Gamma Drive
Pittsburgh, PA 15238-2989 USA
Phone 412/963-0303 Fax 412/963-7620
www.sauereisen.com

Appendix 06: Thermostat set-point specifications

Thermostats (28 V)	Specifications	#*
TEC cooler	Set-point +40 C closing, +45 C for opening Comepa Model 45 Order number: Comepa 4701BHY045040	12
Accu Flight Control	Set-point +45 C closing, +55 C for opening Comepa Model 45 Order number: Comepa 4701BHY055045	12
Start-up heater & Cold-orbit heater	Set-point +60 C closing, +80 C for opening Comepa Model 45 Order number: Comepa 4701BHY080060	16
Liquid line health heater	Set-point +32 C closing, +54 C for opening, Honeywell TS 701 Part number 701S090A130A	16
Thermostats (120 V)	**Specifications**	**#**
Tracker radiator	Set-point - 35 C closing, -25 C for opening, Honeywell TS 705 G311P641/03705S-13A005	24

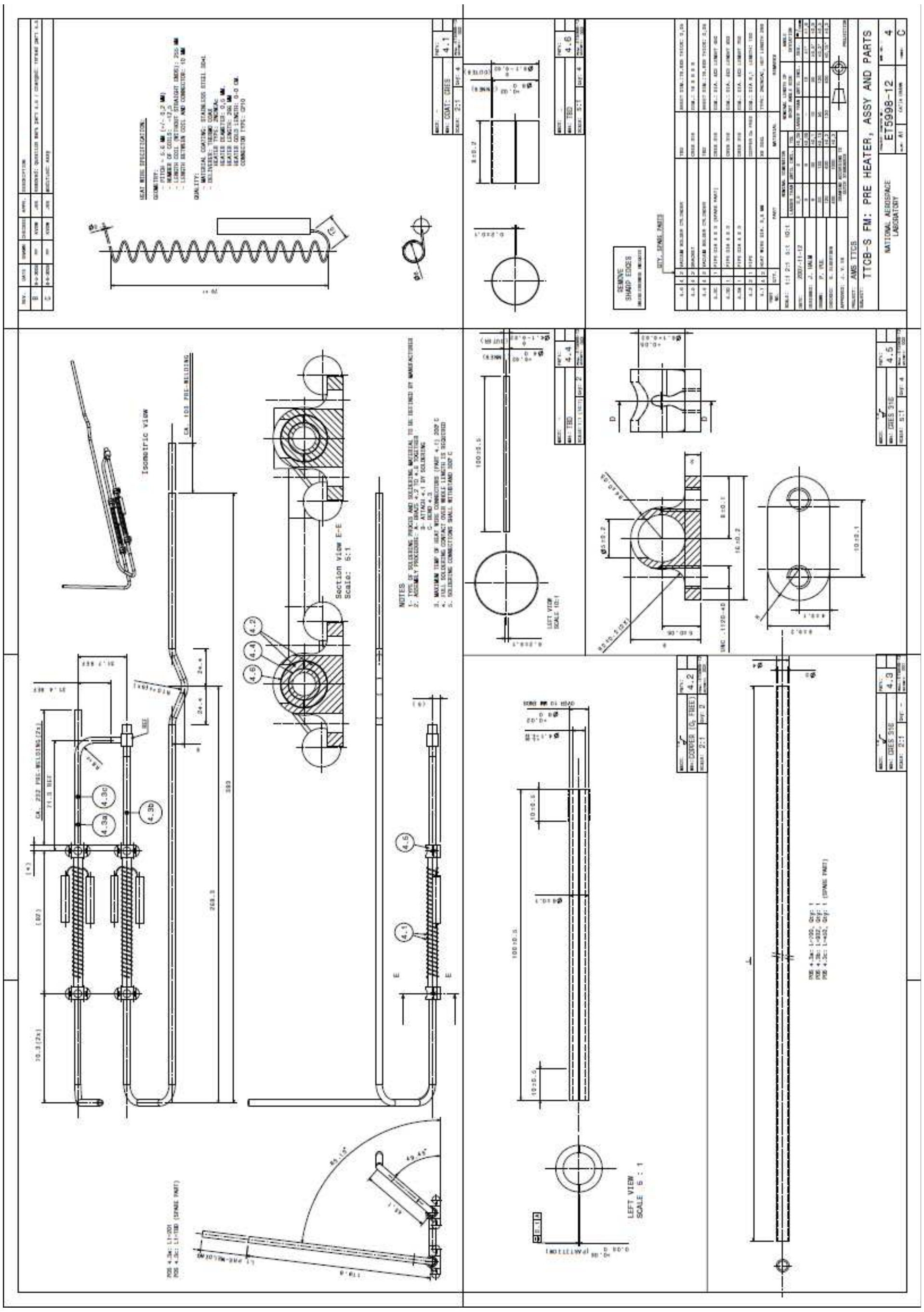
*The numbers are flight numbers

Appendix 07: Terminal block specifications

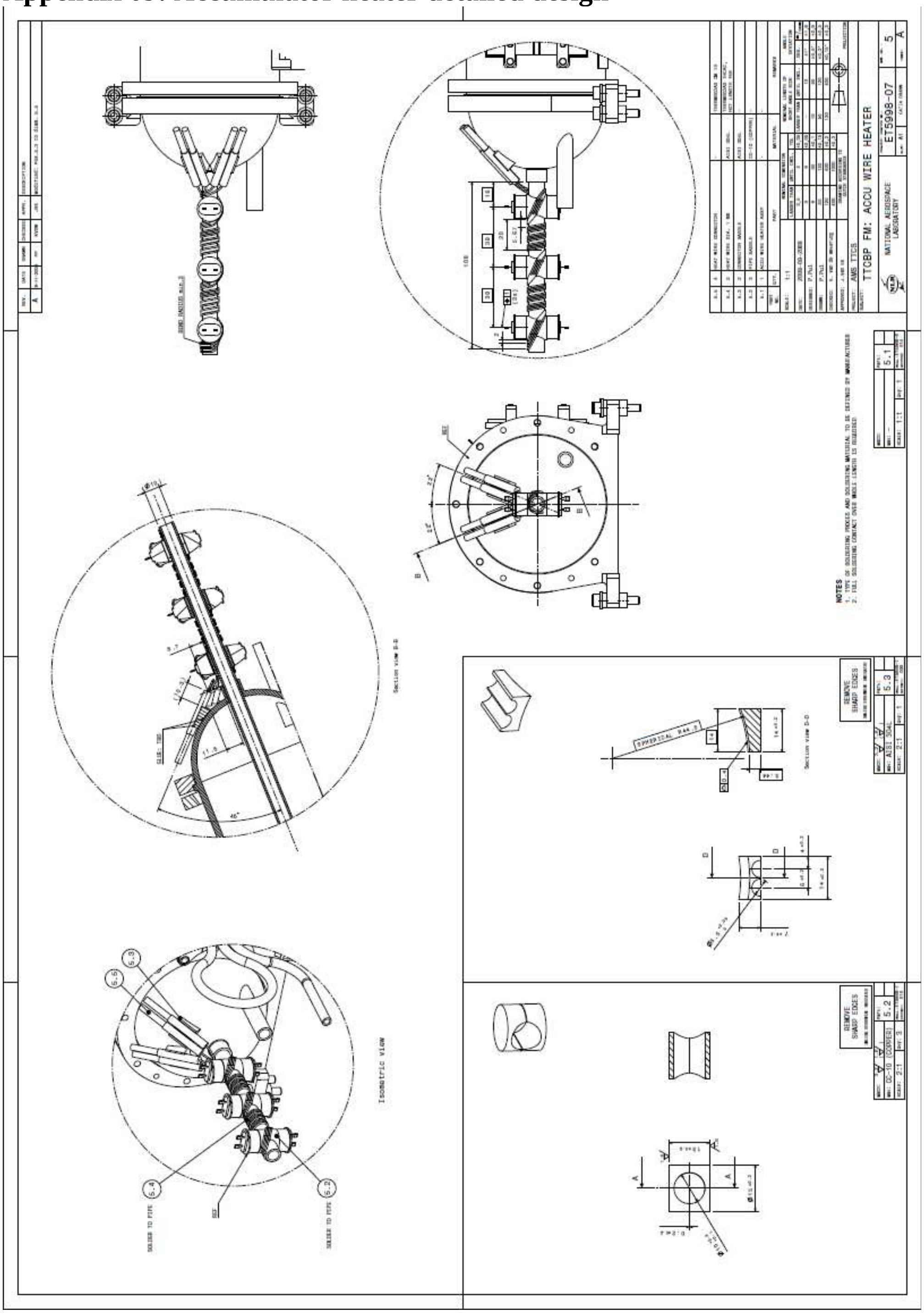
Terminal Blocks	Specs Amphenol	Number	Remarks
TTCS Liquid line heaters	M81714/6-DE1	8	2 near each condenser manifold
120 V Tracker radiator heaters	M81714/1-DE1	4	1 near each condenser manifold

The numbers mentioned are flight numbers.

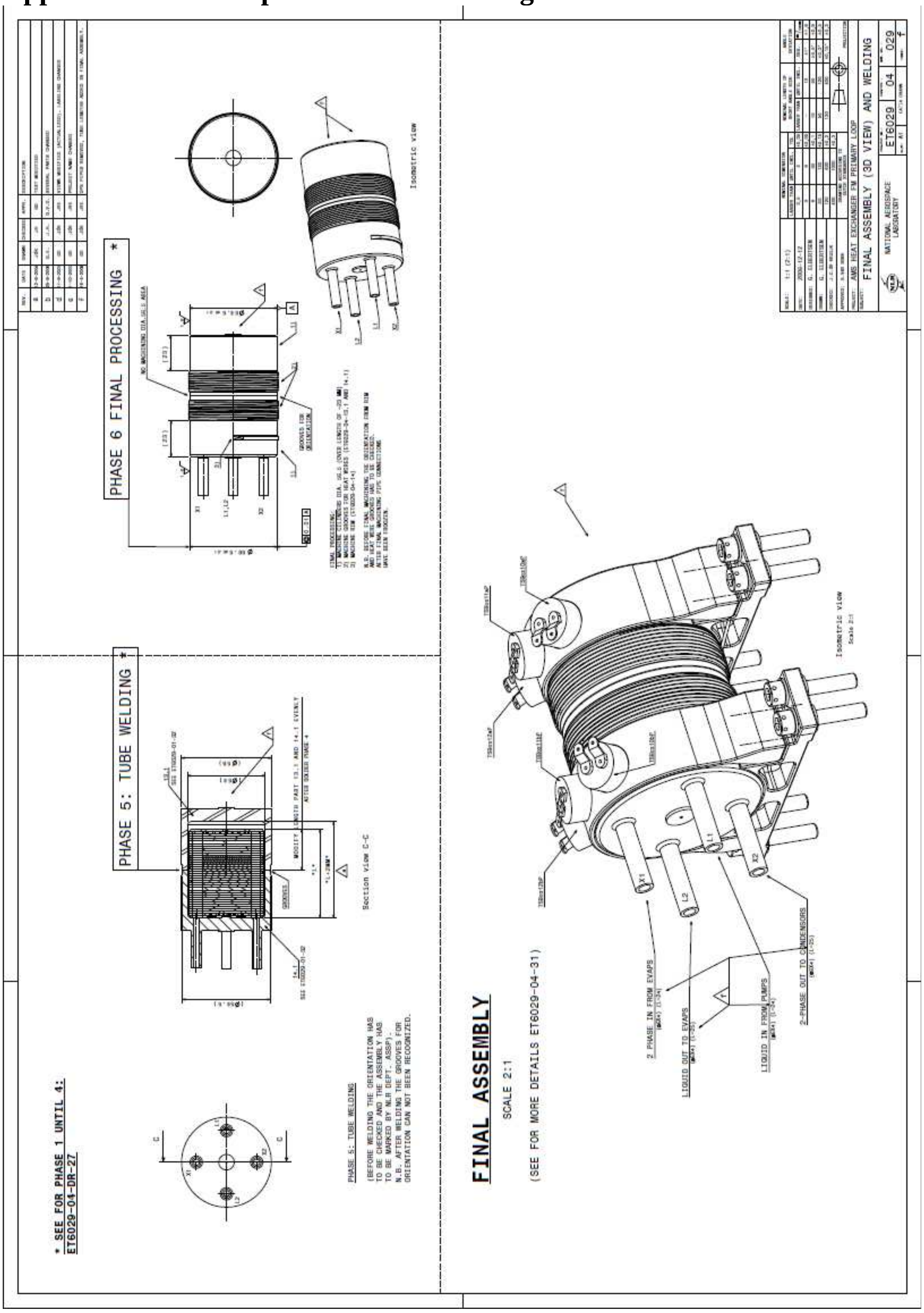
Appendix 08: Pre heater detailed design



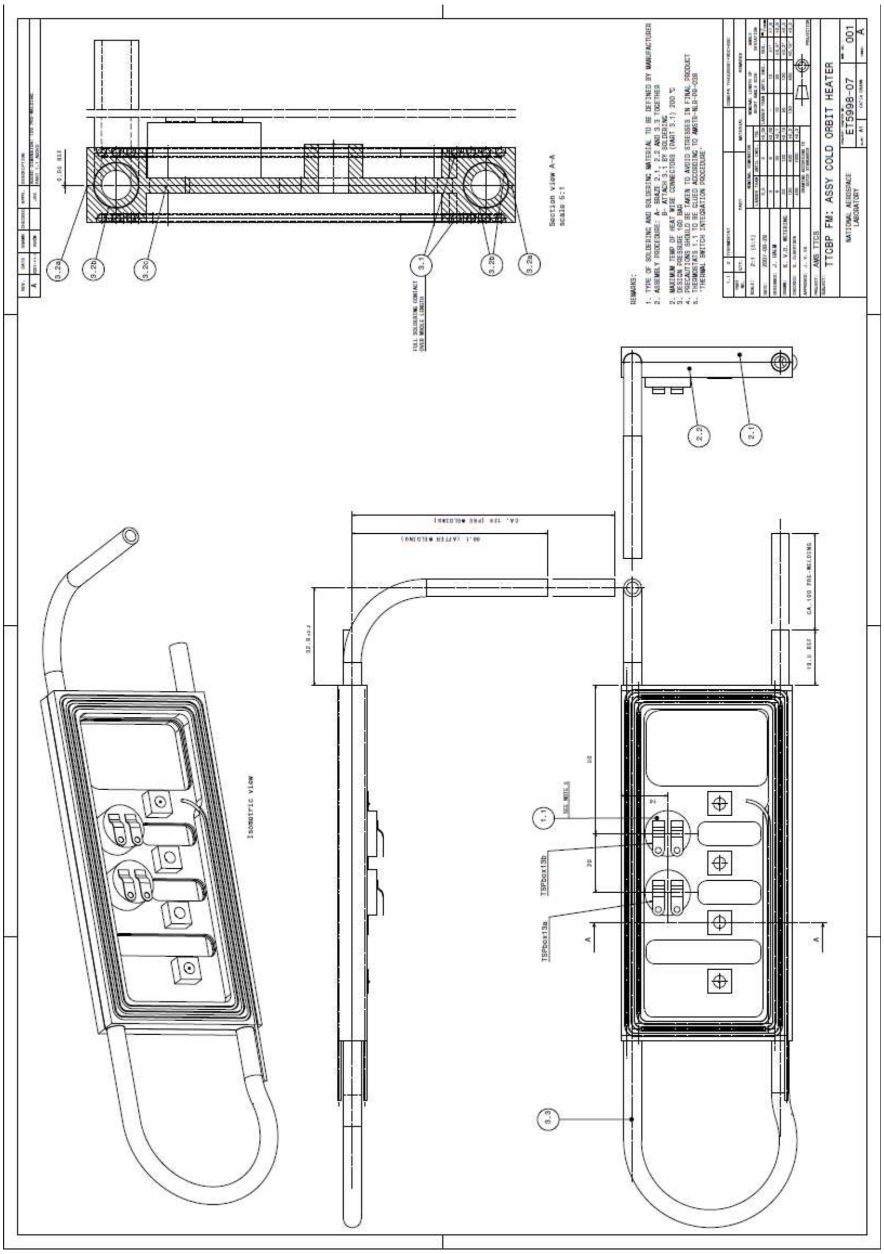
Appendix 09: Accumulator heater detailed design



Appendix 10: Start-up heater detailed design



Appendix 11: Cold orbit heater detailed design



Appendix 12: TTCB-P Cabling schematics (with TS indications)